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# Numerical Electromagnetic Engineering Design System (NEEDS 3.1) Workstation User's Manual

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Naval Command, Control and
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**NAVAL COMMAND, CONTROL AND OCEAN SURVEILLANCE CENTER**
**RDT&E DIVISION**
**San Diego, California 92152-5001**

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## ADMINISTRATIVE INFORMATION

The work detailed in this report was performed for the Naval Sea Systems Command by the Naval Command, Control and Ocean Surveillance Center, RDT&E Division, Applied Electromagnetics Branch, Code 851. Funding was provided under Program Element 0603563N.

Released by
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# 1. INTRODUCTION

The ship electromagnetic (EM) environment today is very complex (Li, Logan, & Rockway, 1988). In addition, the ship EM environment has become a critical design resource as weapons and sensors have become more powerful, more sensitive to upset, and have expanded to make more sophisticated use of the EM spectrum. The task of integrating all the EM radiating and receiving systems into the topside of a Navy ship is very formidable. This task requires a broad and well-founded background in electrical and electronics engineering, as well as a practical knowledge of Navy ships, Navy operating procedures, the shipboard operating environment, Navy equipments, and required system performance. Ship designers must address the following key issues:

1. Predicting the EM environment of new ship designs, major modernizations, or overhauls
2. Assessing the EMI impact of that environment on system performance and, hence, ship mission capabilities.

Since its start in the late 1960s, computational electromagnetics (CEM) has become a powerful, widely used tool for the design of electromagnetic systems. Computational electromagnetics is that branch of electromagnetics that routinely involves using a computer to obtain results. It is a complementary tool to the classical techniques of experimental observation and mathematical analysis. Because of the complexity of the systems involved, the application of analytical techniques has limited its use in ship design. Because of the physical size of ships, scale modeling is used to conduct an empirical study. Scale brass modeling has been the principal approach to support the design of the shipboard communication antennas. There are a number of drawbacks to the use of scale models. Scale models are time-consuming to build, difficult to rapidly modify, and limited in application. Navy ship design is becoming increasingly automated. The use of scale modeling techniques is not consistent with the concurrent engineering approach currently applied to the ship design process. The use of computer-aided design (CAD) technology is accelerating the ship design process. There is greater emphasis on reducing development time and improving the design efficiency. The emphasis is on prototyping on computers rather than in the laboratory. Finally, scale models are usually limited to perfect conductors, since non-perfect conductors (i.e., composite materials) have nonlinear frequency-dependent electric and magnetic properties. The Navy is making increased use of composite materials in ship retrofits and is planning to use composites extensively in the next generation of Navy ships. Thus, the role of CEM is becoming increasingly critical to the ship design process.

Several techniques are available for analyzing the scattering of electromagnetic fields by an object. These techniques include Method of Moments (MoM). The MoM technique can be effectively used for low-frequency situations where the size of objects is small compared to a wavelength. The Numerical Electromagnetic Code - Method of Moments (NEC-MoM), Version 4.0, is the principal computational tool for determining the shipboard EM environment in the high frequency (HF) through very-high-frequency (VHF) bands. The use of the NEC-MoM for antenna system and electromagnetic environment evaluation is a lengthy, tedious, and error-prone process. NEC-MoM requires rigidly defined inputs and produces large masses of output data. The NEC-MoM Workstation, Numerical Electromagnetic Engineering Design System (NEEDS 3.1), was developed to assist in making the method-of-moment process less tedious and more error-free.

This manual assists the user with the operation of NEEDS 3.1. It is a supplement to the Numerical Electromagnetics Code - NEC-4 Method of Moments, Part I: User's Manual (Burke, 1992).

For programmer's reference, consult the companion report to this manual, Numerical Electromagnetic Engineering Design System (NEEDS 3.1) Workstation Programmer's Manual (Lam, Rockway, Russell, & Wentworth, 1995). This programmer's manual contains detailed information on how the NEEDS 3.1 code was written, including source code listings.

# 2. GETTING STARTED

## 2.1 SYSTEM REQUIREMENTS

NEEDS 3.1 was designed to run on an Intergraph workstation with a C400 processor under the UNIX operating system and the X Window System. NEEDS 3.1 also requires the installation of the following shared libraries:

1. libXm_s.a
2. libXt_s.a
3. libX11_s.a
4. libc_s.a

These libraries are normally found in the "/usr/lib" directory. At least 20 MB of disk space should be allowed for the NEEDS 3.1 executable file and various auxiliary files.

NEEDS 3.1 also requires the "nec4s" executable file and NCSA Mosaic for X Windows. NEEDS uses Mosaic as a hypertext Help facility. The user should verify that the directories in which Mosaic and "nec4s" reside are included in the user's path.

## 2.2 INSTALLATION

To install NEEDS, the user should first change to the location in which the NEEDS 3.1 directory will reside. The files can then be extracted from the tape by typing **tar xvf /dev/rmt/mt6**.

The appropriate device name can be substituted for "/dev/rmt/mt6". This command will create a new directory called "needs3.1" and will copy all the necessary files into the "needs3.1" directory.

The file NEEDS (all caps) is the app-defaults file for NEEDS 3.1 and must be put in the system app-defaults directory. This is usually "/usr/lib/X11/app-defaults/". The app-defaults file contains the default values for the application's X resources.

To build NEEDS 3.1, the user will need to build two libraries: Simple Raster Graphics Package (SRGP) and XGraphics. The source code for these two libraries are located in the "srgp" directory and the "xgraphics" directory, respectively. After these two libraries have been created, NEEDS 3.1 should be built by using the Makefile located in the "needs3.1" directory.

## 2.3 PROGRAM EXECUTION AND CUSTOMIZATION

To run NEEDS, simply type **needs** while in the "needs3.1" directory.

NEEDS 3.1 can be customized by altering the ".Xdefaults" file that is located in the home directory. Editing this file is the standard way of configuring X-based applications. By specifying the X resources associated with NEEDS 3.1, the program's look and feel can be controlled. This includes fonts and colors. The following line demonstrates how the color of all the list boxes might be changed in NEEDS 3.1:

```
NEEDS*XmList.background: gray
```

Since NEEDS 3.1 uses the Motif widget set, it would be beneficial to have some knowledge of Motif and the X Window System if any extensive customization of the interface is planned.

Included with the NEEDS Workstation is a sample of the file ".Needs". This file must exist in the user's home directory. It allows the user to specify the print paths, where the XGraphics font directory is, and a current project name. An example is:

```
MOM_PRINT_GRAPHICS=lpr -Pfuji_ps
MOM_PRINT_TEXT=lpr -Pfuji_text
XGRAPHICS_FONT_DIR=/usr2/xgraphics/data
MOM_FILE=/usr3/jlam/master/120as.mom
```

The ".Needs" file has to be customized by the user and then put in the user's home directory. "MOM_PRINT_GRAPHICS" refers to a postscript printer, "MOM_PRINT_TEXT" refers to a text (non-Postscript) printer, "XGRAPHICS_FONT_DIR" refers to the font locations for the XGraphics library, and "MOM_FILE" is the current project filename. The "MOM_FILE" file can be blank initially.

### 2.4 NEEDS WORKSTATION FILES

A variety of sample problems are provided. These NEEDS Workstation files have the extension "*.nec*". The sample problem files include the examples one through five of the NEC-4 User's Manual. Also included is a Coast Guard 120 ship, "120as.nec".

The "NEC-MOM" output files have the extension "*.out*". Various filtered output products have the following extensions:

1. All: *.out*
2. Impedance: *.rz*
3. Admittance: *.ra*
4. Currents: *.rcr*
5. Charges: *.rq*
6. Coupling: *.rcp*
7. Near Electric Field: *.rne*
8. Near Magnetic Field: *.rnm*
9. Radiation Patterns: *.rpt*

The files with extension "*.html*" are Mosaic source files for the help screens.

## 3. MAIN WINDOW

The Method-of-Moments process consists of three major modules. The three modules are:

1. Problem definition
2. Computation
3. Solution display

The Problem Definition module consists of defining the geometry of the antenna and surrounding structure, specifying the electromagnetic parameters such as frequency and sources, and deciding on what outputs to produce and what algorithms to use. The Computation module is where the NEC-MoM computing occurs. The Solution Display module consists of "thought-enhancing" output products such as animated visualization, engineering graphs, and reports.

NEEDS 3.1 supports the three major modules of the Method-of-Moments process. The NEEDS 3.1 Main Menu bar is structured around the concept of the three major modules. As displayed in figure 1, the Menu Bar is located at the top of the NEEDS application, just below the Title Bar. The Title Bar includes the NEEDS version number and the current project file.

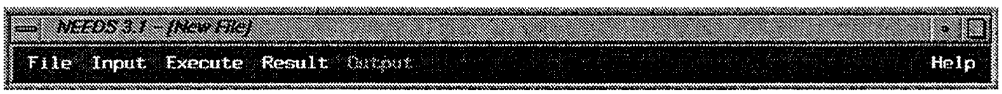


**Figure 1**. NEEDS 3.1 Main Menu.

A filing capability is provided under the File menu. Input consists of defining the geometry of the antenna, specifying the electromagnetic parameters, and choosing output products. To support the computation module, NEEDS 3.1 provides explicit diagnostic capability for the user to review the validity of the NEEDS problem definition and also translates the NEEDS problem definition into a NEC 4.0 data input. The NEC output for a ship modeling problem can be considerable. In support of the Solution Display, NEEDS 3.1 provides the ability to view the tabular output. The tabular results can also be displayed in user-specified engineering graphs. In addition, 3-D visual displays are available to enhance understanding of the output.

Each of the options in the Main Menu are described in the following sections.

# 4. FILE

There are two types of files that are associated with the NEEDS Workstation. The NEC 4.0 data file for the project is stored in a file with the extension "*.nec*". The output from NEC 4.0 is stored in a file with extension "*.out*". There are also a variety of files that are extracted products of "*.out*". These files are described in section 7.0. The File menu allows the user to open and save project files. The menu items and their functions are as follows:

**Open**—Opens an existing project file. The NEEDS Workstation provides a dialog box for specification of the path and a file name. The "*<ProjectName>*.nec" file is loaded into the NEEDS Workstation, where "*<ProjectName>*" is the file name.

**Save**—Saves the project that is currently active to a file. This saves the project description in the NEEDS Workstation into a corresponding NEC 4.0 data file ("<ProjectName>.nec"). This option uses a previously defined project file name if one exists; otherwise, the user is prompted for a new file name.

**Save as**—Saves the project that is currently active to a new filename. The user is prompted for a new filename.

**New**—Opens a new project file and assigns the temporary filename untitled. Only default parameters are included in the definition.

**Close all**—Closes all open windows.

**Exit**—Closes the NEEDS Workstation. The user will be prompted whether to save a newly created or modified problem.

# 5. INPUT

Input consists of three submenus: Comments, Geometry Description, and Edit Control Description. Each of the Input submenu options are described in detail in the following subsections.

The general input dialog window follows the Naval Sea Systems Command (NAVSEA)-defined EM Engineering Common User Interface (CUI) (Rockwell, 1992). An example of a graphical user interface (GUI) used for the Node Coordinates in NEEDS 3.1 is displayed in figure 2. On a general dialog window, there are several common push buttons. Not all of the dialog windows contain all of the following push buttons.

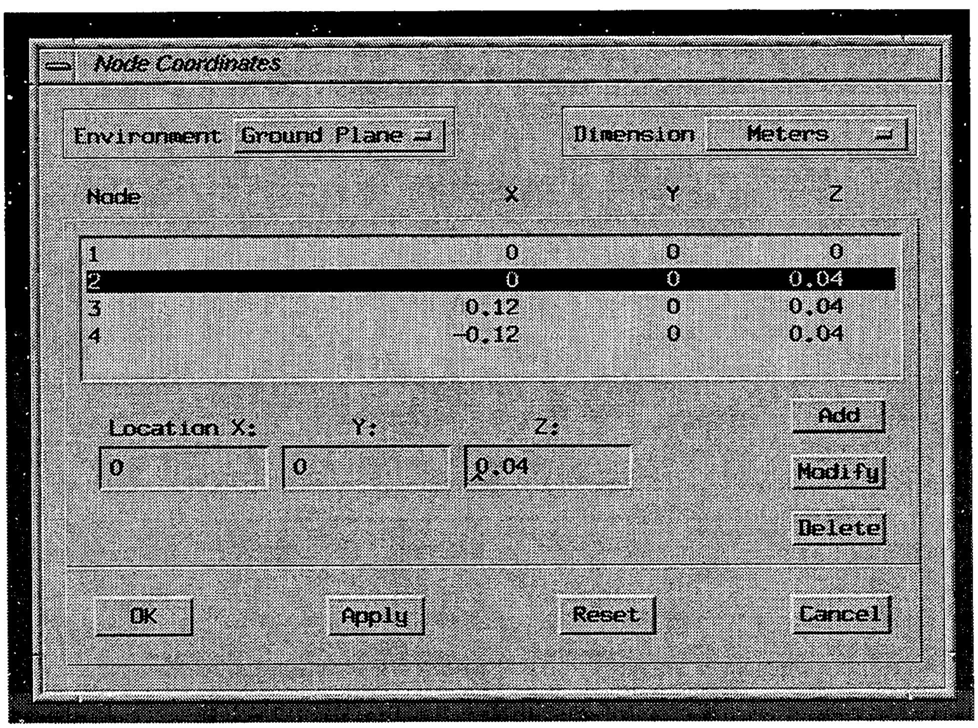


**Figure 2.** Node Coordinates Window.

Some or all of the following push buttons are located at the bottom of dialog windows. Their functions are as follows:

**Ok**—Accepts all of the user inputs and dismisses the dialog window.

**Apply**—Accepts all of the user inputs, but does not close the dialog window.

**Reset**—Ignores all of the user inputs since the dialog box appeared or since the user hit the Apply button (whichever happened last), but does not close the dialog window.

**Cancel**—Ignores all of the user inputs since the dialog window appeared or since the user hit the Apply button (whichever happened last) and closes the dialog window.

The {ESC} key also closes a given dialog window. User inputs will be discarded.

At the top of many dialog windows is a box that lists the defined parameters. Features of this list box include:

1. The number of the highlighted entry and the total number of entries is displayed on top of the list box.
2. Clicking on an entry in the list box fills the text boxes with the parameter data for that entry.

At the side of many dialog boxes are the following push buttons. Their functions are as follows:

**Add**—Adds parameters in text boxes to list box.

**Modify**—Modifies the highlighted entries with the current entries in the text boxes. If more than one entry has been highlighted and an entry is made to any of the text boxes, this entry will then modify appropriately all of the highlighted entries in the list box. Shift + click or shift + arrow key extends the selection from the previously selected entry to the current entry. CTRL + click selects or deselects an entry from the list.

**Delete**—Deletes the current highlighted entries in the list box.

Shift + click or shift + arrow key extends the selection from the previously selected entry to the current entry. CTRL + click selects or deselects an entry from the list.

## 5.1 COMMENTS WINDOW

This window inserts text in the program output for a title or documentation. See page 20 of the NEC 4.0 User's Manual (Burke, 1992) for further information.

## 5.2 GEOMETRY DESCRIPTION

The General Description submenu options and the hot keys to access each option are as follows:

1. Node coordinates: Ctl + N
2. Straight wires: Ctl + W
3. Tapered wires: Shf + W
4. Catenary wires: Ctl + C
5. Wire arc: Ctl + A
6. Helix or spiral
7. Mesh: Ctl + Z
8. Surface patches

9. Multiple patches
10. Transformations: Ctl + T
11. Rotations: Shf + T
12. Reflections: Ctl + R
13. Spiral ordering . . .
14. CAD interface
15. Edit card order

The following sections describe the objective and user input parameters of each window. Additional information may be provided.

### 5.2.1 Node Coordinates Window

This window defines the coordinates of geometry nodes. Table 1 defines the Node Coordinate Window parameters.

**Table 1**. Node Coordinate Window parameters.

| Parameter | Definition |
|---|---|
| Location X | X coordinate of node |
| Location Y | Y coordinate of node |
| Location Z | Z coordinate of node |

The options for the Environment list box include free space and ground plane. The options for the Dimension list box include meters, centimeters, feet, and inches. If a ground is specified, an intrinsic diagnostic checks if nodes are located below ground.

### 5.2.2 Straight Wires (GW) Window

This window generates a straight wire as a string of uniform segments. Table 2 defines the Straight Wires Window parameters. See page 35 of the NEC 4.0 User's Manual (Burke, 1992) for further information.

**Table 2**. Straight Wires (GW) Window parameters.

| Parameter | Definition |
|---|---|
| Tag | Tag number assigned to the straight wire |
| Node of End 1 | Node of first end of the straight wire |
| Node of End 2 | Node of second end of the straight wire |
| Number of segments | Number of segments into which the wire will be divided |
| Radius | Wire radius |

**5.2.2.1 Additional Information.** Intrinsic diagnostics check that all nodes are one or greater, that the Number of Segments is greater than zero, and that the Radius is greater than zero. If the Radius is set to zero, NEEDS automatically resets the radius to 0.001.

The tag number, Tag, is for later use when a segment must be identified, such as when connecting a voltage source or lumped load to the segment. If no need is anticipated for a reference to the segments of a wire, a Tag can be blank. Any number except zero can be used as a Tag.

If two wires are electrically connected at their ends, the identical coordinates should be used for the connected ends to ensure that the wires are treated as connected for current interpolation. The only significance of differentiating End 1 from End 2 of a wire is that the positive reference direction for current will be in the direction from End 1 to End 2 on each segment making up the wire.

**5.2.2.2 Wire Modeling (NEC 4.0).** A wire segment is defined by the coordinates of its two end points and its radius. Modeling a wire structure with segments involves both geometrical and electrical factors. Geometrically, the segments should follow the paths of conductors as closely as possible, using a piece-wise linear fit on curves. It is usually better to keep the length of a piece-wise linear path approximately equal to that of the continuous curve rather than inscribing or circumscribing the path, although the difference should not be great if the segments are sufficiently short.

The main electrical consideration is segment length relative to the wavelength. Generally, segment length should be less than about 0.1 wavelength at the desired frequency. Somewhat longer segments may be acceptable on long wires with no abrupt changes. Shorter segments, 0.05 wavelengths or less, may be needed in modeling critical regions of an antenna. The size of the segments determines the resolution in solving for the current on the model, since the current is computed at the center of each segment. Extremely short segments can be used with NEC 4.0, subject to limitations related to the wire radius.

The wire radius relative to wavelength is limited by the approximations used in the kernel of the electric field integral equation. NEC uses the thin-wire approximation. This neglects transverse currents on wires and assumes that the axially directed current is uniformly distributed around the segment surface. The acceptability of these approximations depends on both the value of wire radius in wavelengths and the tendency of the excitation to produce circumferential current variation. Unless wire diameter in wavelengths is much less than 1, the validity of these approximations should be considered.

The accuracy of the solution for the axial current is also dependent on segment length to wire radius ratio due to approximations in the evaluation of the thin-wire kernel. Small values of segment length to wire radius ratio may result in oscillations in the computed current near free wire ends, voltage sources, lumped loads, or changes in wire radius. Obvious instabilities in the current near wire ends may occur for segment length to wire radius ratios less than about 0.5. Ratio values several times larger should be used, if possible.

The current expansion used in NEC enforces conditions on the current and charge density along wires, at junctions, and at wire ends. For these conditions to be applied properly, segments that are electrically connected must have coincident end points. If segments do not intersect at their ends, NEC will not allow current to flow from one segment to the other. A tolerance is allowed in determining connections, with segments considered connected if the separation of their ends is less than 0.001 times the length of the shortest segment. When possible, however, identical coordinates should be used for connected segment ends.

The angle of intersection of wire segments in NEC is not explicitly restricted. Hence, the acute angle may be made so small as to place the observation point on one wire segment within the volume of another wire segment. Such overlapping segments cannot be modeled accurately with thin-wire approximation. Numerical studies have shown increasing errors when the center point of one segment approaches within a radius length of the surface of an adjacent segment. Even with larger angles of intersection, the details of the current distribution in the region of a bend cannot be represented accurately in the thin-wire approximation, but the results for current should be accurate at a distance from the bend.

Other rules affecting wire segment models include:

1. Segments may not overlap, since the division of current between two overlapping segments is indeterminate. Overlapping segments may result in a singular matrix equation.
2. A segment is required at each point where a network connection or voltage source will be located. This may seem contrary to the idea of an excitation gap as a break in a wire. However, a continuous wire across the gap is needed so that the required voltage drop can be specified as a boundary condition.
3. The minimum separation of parallel wires is limited by thin-wire approximation. The actual error versus separation has not been well determined, but a limit on the separation between wire axes of two or three times the largest diameter seems reasonable. When parallel wires are close together, they should, if possible, have equal segment lengths with the segment ends aligned, to avoid incorrect current perturbations from offset match points and segment junctions.

It is good modeling practice to vary parameters in a model to gain an understanding of the effect on results. Increasing the number of segments, perhaps by a factor of two, will give an indication of the convergence error in the moment-method solution. Changing the frequency slightly can also reveal sensitivity of the results. In the vicinity of a very sharp frequency resonance, small modeling errors, resulting either from numerical errors or simplifications made to the physical model, can result in large changes in antenna impedance or gain. In such a case, the best approach may be to compute results over a band of frequencies rather than looking at any one frequency. There are also some self-consistency checks that can be obtained from the NEC output. These include checking how well the boundary condition on the electric field is being satisfied along wires, the balance of input and radiated power, and reciprocity. When possible, these checks should be considered to help validate a model.

### 5.2.3 Tapered Wires (GW) Window

This window generates a tapered wire. Table 3 defines the Tapered Wires Window parameters. See pages 24-25 of the NEC 4.0 User's Manual (Burke, 1992) for further information.

**Table 3**. Tapered Wires Window parameters.

| Parameter | Definition |
|---|---|
| Tag | Tag number assigned to the tapered wire |
| Node of End 1 | Node of first end of the tapered wire |
| Node of End 2 | Node of second end of the tapered wire |
| Number of Segments | Number of Segments into which the wire will be divided. If Type equals 2, this parameter is computed |
| Type | Flags to select the input form for tapered segment lengths |

**Table 3.** Tapered Wires Window parameters. (Continued)

| Parameter | Definition |
|---|---|
| 0 | Specifies the Ratio of Segment Lengths (RDEL) |
| 1 | Specifies the Length of the First Segment (DEL1) |
| 2 | Specifies the Lengths of the First and Last Segments |
| Ratio of Segment Lengths | If Type = 0, then Ratio of Segment Lengths is the ratio of the length of segment i+1 to the length of segment i. Length of First Segment and Length of Last Segment are not used if Type = 0 |
| Start Radius | Wire Radius of First Segment |
| End Radius | Wire Radius of Last Segment |
| Start Segment Length | If Type is greater than zero, Length of the First Segment; The length must be greater than zero and less than the total wire length |
| End Segment Length | If Type of Taper = 2, Length of Last Segment on the wire; The Segment Length Ratio and Total Number of Segments will be computed to fill the total wire length. |

**5.2.3.1 Additional Information.** Intrinsic diagnostics check that all nodes are one or greater, that the number of segments is greater than zero, and that the radius is greater than zero. If the radius is set to zero, NEEDS automatically resets the radius to 0.001.

The ratio of the radii of adjacent segments, RRAD, is

$$RRAD = (RAD2/RAD1)^{1/(NS-1)},$$

where RAD1 is the Start Radius, RAD2 is the End Radius, and NS is the Number of Segments.

If the total wire length is L and the ratio of the length of segment, i+1, to that of segment, i, is RD, then the length of the first segment is

$$D_1 = L\,(1 - RD) / (1 - RD^{NS}).$$

Also,

$$D_1 = L/NS, \text{ if } RD = 1.$$

When the initial segment length is input (Type of Taper = 1), the length ratio, RD, is computed by solving the above equation by iteration. When the initial and final segment lengths are specified (Type of Taper = 2), the length ratio and number of segments are computed as

$$RD = (L - D_1)/(L - D_2), \quad NS = 1 + \mathrm{Log}(D_2/D_1)/\mathrm{Log}(RD).$$

NS is rounded to an integer. RD is then recomputed to fit the total wire length with the specified initial segment length. The resulting final segment length will differ slightly from the requested value due to rounding NS.

### 5.2.4 Catenary Wires (CW) Window

This window generates a wire between two points with the catenary shape. Table 4 defines the Catenary Wires Window parameters. See pages 21-22 of the NEC 4.0 User's Manual (Burke, 1992) for further information.

**Table 4.** Catenary Wires (CW) Window parameters.

| Parameter | Definition |
|---|---|
| Tag | Tag number assigned to the catenary wire |
| Node of End 1 | Node of first end of the tapered wire |
| Node of End 2 | Node of second end of the tapered wire |
| Number of Segments | Number of Segments into which the wire will be divided; If Type equals 2, this parameter is computed |
| Radius | Wire radius |
| Type | Flags to select the input form for tapered segment lengths |
| 1 | Specifies height at a point along the catenary |
| 2 | Specifies sag at a point along the catenary |
| 3 | Specifies the total length of the catenary |
| Distance | Distance depends on Type |
| Type 1 | Horizontal distance from first end to under the catenary |
| Type 2 | Horizontal distance from first end to under the catenary |
| Type 3 | Length of the catenary between end points |
| Height | Height depends on Type |
| Type 1 | Height of the catenary at the point defined by the distance |
| Type 2 | Sag of the catenary below a straight-line path at the point defined by the Distance |

**5.2.4.1 Additional Information.** Intrinsic diagnostics check that all nodes are one or greater, that the number of segments is greater than zero, and that the radius is greater than zero. If the radius is set to zero, NEEDS automatically resets the radius to 0.001.

The wire segments are inscribed within the catenary, so the total segment length will be somewhat less than the catenary length. The total length of the catenary is divided into equal sections defined by the Number of Segments, and a segment subtends each of these sections. Thus, the segments will have nearly equal lengths, but segments on a part of the catenary with greater curvature will be somewhat shorter than on straighter sections. The catenary length and total wire length are printed in the NEC output.

For Type equal to 1 or 2, the height or sag at the point defined by Distance sets the amount of curvature in the catenary. This point should not be too close to either end point, and the Height should be less than the height of a straight line between Node of End 1 and Node of End 2. If the Height is above the straight line, the catenary will turn upside down.

For Type equal to 3, the length set by Distance should be greater than or equal to the straight-line distance between the end points. If a length less than the straight line between the ends is entered, a straight wire between the end points will be generated.

See information on wire modeling in section 5.2.2.

### 5.2.5 Wire Arc (GA) Window

This window generates a circular arc of wire segments. Table 5 defines the Wire Arc Window parameters. The arc is in the x-z plane, centered on the y-axis. See page 23 of the NEC 4.0 User's Manual for further information.

**Table 5**. Wire Arc (GA) Window parameters.

| Parameter | Definition |
|---|---|
| Tag | Tag number assigned to the wire arc |
| Number of Segments | Number of segments into which the arc will be divided |
| Arc Radius | Center of the arc is at the origin and the axis is the y-axis, so the arc is in the x-z plane |
| Angle of End 1 | Angle of the first end of the arc measured from the x-axis in a left-hand direction about the y-axis (degrees) |
| Angle of End 2 | Angle of the second end of the arc |
| Wire radius | Wire radius |

**5.2.5.1 Additional Information.** Intrinsic diagnostics check that all nodes are one or greater, the number of segments is greater than zero, and the radius is greater than zero. If the radius is set to zero, NEEDS automatically resets the radius to 0.001.

The segments generated by wire arc form a section of polygon inscribed within the arc. If an arc in a different position or orientation is desired, the segments may be moved with a transformation.

Use of a wire arc to form a circle will not result in symmetry being used in the calculation. However, a wire arc is a good way to form the beginning of a circle to be completed by rotation.

See information on wire modeling in section 5.2.2.

**5.2.5.2 Small-Loop Modeling (NEC 4.0).** Although the conditions leading to errors with electrically short segments have been corrected in NEC 4.0, there can still be a loss of precision or failure of the solution for small loops. The problem is that the solution for small loops using point matching and localized current expansion functions in NEC can result in an ill-conditioned matrix. The problems seem to depend on whether the loop contains a voltage source or is excited by external coupling. The single precision NEC 4.0 fails at a loop circumference of approximately 0.002 wavelength.

If the loop does not contain a voltage source, but is excited by external coupling the errors due to the point-matched solution in NEC, combined with the ill-conditioned matrix of a small loop, the result may be an incorrect solution with large currents circulating in the loop. This problem occurs when the loop is excited by the field due to nearby charge concentrations on wire ends. Use of double precision may not improve the solution, since the main problem is the errors due to point matching. The use of loop basis and weighting functions is the only way to avoid these errors. Otherwise, cases of close coupling of a small loop to wire antennas should be avoided. Fortunately, the circulating currents do not radiate strongly until they become large.

### 5.2.6 Helix or Spiral (GH) Window

This window generates a wire helix or a log or Archimedes spiral. Table 6 defines the Helix or Spiral Window parameters. See page 29 of the NEC 4.0 User's Manual (Burke, 1992) for further information.

**Table 6**. Helix or Spiral (GH) Window parameters.

| Parameter | Definition |
|---|---|
| Tag | Tag number assigned to the helix or spiral wire |
| Number of Segments | Number of segments in the spiral |
| Number of Turns | Number of turns in the spiral (may be fractional). A positive number will produce a right-hand helix relative to t-axis, and a negative number will produce a left-hand helix |
| Z-Length | Length of the spiral or helix along the z-axis from z=0 |
| Helix Start Radius | Radius of the spiral at the starting end |
| Helix End Radius | Radius of the spiral at the final end of the spiral |
| Spiral Start Radius | Radius of the wire at the starting end of the spiral |
| Spiral End Radius | Radius of the wire at the final end of the spiral |
| ISPX | Equals zero for a log spiral and one for an Archimedes spiral. Either one can be used for a helix with equal start and end radii |

**5.2.6.1 Additional Information.** Intrinsic diagnostics check that the number of segments is greater than zero, and that the radius is greater than zero. If the radius is set to zero, NEEDS automatically resets the radius to 0.001.

The segments generated by helix or spiral subtend equal angles with respect to the z- axis. The segments are inscribed within the curve of the spiral. If a spiral in a different position or orientation is desired, the segments may be moved with a transformation.

See information on wire modeling in section 5.2.2.

### 5.2.7 Wire Mesh Surface Window

This window covers a surface with a wire mesh. Table 7 defines the Wire Mesh Surface Window parameters.

**Table 7**. Wire Mesh Surface Window parameters.

| Parameter | Definition |
|---|---|
| Node of Corner 1 | Node of Corner 1 of wire mesh surface |
| Node of Corner 2 | Node of Corner 2 of wire mesh surface |

Table 7. Wire Mesh Surface Window parameters. (Continued)

| Parameter | Definition |
|---|---|
| Node of Corner 3 | Node of Corner 3 of wire mesh surface |
| Node of Corner 4 | Node of Corner 4 of wire mesh surface |
| Number of Wires Corner 1 to 2 | Number of wires on side between Corners 1 and 2 |
| Number of Wires Corner 2 to 3 | Number of wires on side between corners 2 and 3 |
| Area Factor | Determines the wire radius that will be used in the wire grid; If Area Factor = 1, the "equal area" rule is used; In the "equal area" rule, the circumference of the wire times its segment length is equal to the area of a mesh cell; If Area Factor is greater than one, the wire radius will be increased over the radius for an "equal area." |

**5.2.7.1 Additional Information.** Intrinsic diagnostics check that all nodes and the number of wires are one or greater.

Wire Mesh Surface is used to model structures. The structure is divided into quadrilateral or triangular flat regions of any orientation in space. There is no restriction on the shape of the quadrilateral region or its orientation in space as long as it is flat. Knowing the nodes of the corners for each individual region and the number of grid cells required on the sides, the region is converted into a wire grid. In the special case of the triangular region, the nodes of two consecutive corners are the same. The region is divided into grid cells by specifying the number of wires on two adjacent sides.

For triangular regions, there are only three corners, so one of the opposite sides will simply be a vertex. This type of region is defined as one in which Corners 3 and 4 have the same node (i.e., coordinates are the same).

When the OK button is pushed, the wire grid is generated and the required nodes and straight wires are added to Straight Wires and Nodes. Similar wires and nodes are eliminated. The information in Wire Mesh Surface is then erased.

The wire spacing in the grid will depend on the type of structure modeled and the parameters of interest. A generally accepted value is 0.01 wavelength. When impedance and near fields are of interest, a much smaller grid size could be used. However, the choice of grid size must be weighted against the resulting size of the problem (i.e., number of unknowns). The number of unknowns can increase dramatically with a decrease in grid size. For the wire radii of the grid, much of the literature recommends that the "twice surface area rule" be used. In other words, the Area Factor = 2.

**5.2.7.2 Wire Grid Modeling.** Conducting surfaces can sometimes be modeled as wire grids by using the equivalence of a solid conducting surface with a grid having sufficiently small mesh size. Unlike the surface patch model in NEC, based on the magnetic field integral equation, a wire grid can be used to model thin plates, open shells, and finitely conducting surfaces. A single wire grid can represent the exterior of a solid body or both surfaces of a thin conducting plate. The current on the grid will be the sum of the currents that would flow on the opposite sides of the plate. While the information about the currents on the individual surfaces is lost, the total current will yield the correct radiated and near fields.

Wire grid modeling of conducting surfaces has been used with varying success. The earliest applications to the computation of radar cross sections and radiation patterns provided reasonably accurate results. Even computations for the input impedance of antennas driven against grid models of surfaces have often exhibited good agreement with experiments. However, broad and generalized guidelines for near-field quantities have not been developed, and the use of wire grid modeling for near field parameters should be approached with caution. Incorrect circulating currents in the mesh can sometimes be a problem.

Wire grids are generally constructed as a rectangular mesh of segments, although other shapes can be used to fit irregular surfaces. If a preferred direction for current is evident, more wires can be run in that direction. The mesh size should be about 0.1 wavelength on a side, or smaller. This size is not too critical. A larger mesh, perhaps with more than one segment per side, might be used on surfaces far from the driven antenna. The grid should include wires outlining the corners of the structure. The rules for wire modeling, including size of radius with respect to wavelength and segment to radius ratio should be followed.

The choice of wire radius in the mesh is somewhat uncertain since it does not correspond to any physical characteristic of the surface. It has been found that a mesh of thin wires has excess inductance and not enough capacitance when compared with a solid surface. To correct this difference, it is generally recommended that the segment radius be chosen so that the wire diameter = d, where d is the separation of wires in the mesh. This condition is sometimes called "the equal area rule" since the surface area of the wires in one direction on the grid is equal to the area of one side of the surface. The advantage of the "equal area rule" has been demonstrated for a cylinder formed with parallel wires (Ludwig, 1987); other results also support this rule (Moore and Pizer, 1984).

### 5.2.8 Surface Patches (SP, SC) Window

This window inputs parameters of a single surface patch. For some patch options in NEC 4.0, the multiple patch quadrangle surface must be followed by the surface patch description to enter additional parameters. Table 8 defines the Surface Patches Window parameters. See pages 39-43 of the NEC 4.0 User's Manual (Burke, 1992) for further information.

**Table 8**. Surface Patches (SP, SC) Window parameters.

| Parameter | Definition |
|---|---|
| Type | Selects the option for defining the surface patch as follows: |
| 1 | Rectangular patch |
| 2 | Triangular patch |
| 3 | Quadrilateral patch |
| Node of Corner 1 | Node of Corner 1 of surface patch |
| Node of Corner 2 | Node of Corner 2 of surface patch |
| Node of Corner 3 | Node of Corner 3 of surface patch |
| Node of Corner 4 | Node of Corner 4 of surface patch |

**5.2.8.1 Additional Information.** Intrinsic diagnostics check that all nodes are one or greater.

For the patches, the outward normal vector is determined by the ordering of Corners 1, 2, and 3 and the right-hand rule.

If the sides from Corner 1 to Corner 2, and from Corner 2 to Corner 3 of the rectangular patch are not perpendicular, the result will be a parallelogram.

If the four corners of the quadrilateral patch do not lie in the same plane, the NEC 4.0 computation will terminate with an error message.

Since NEC 4.0 does not integrate over patches except at a wire connection, the patch shape does not affect the results. The only parameters affecting the results are the location of the patch centroid, the patch area, and the outward unit normal vector. For a shapeless patch, these are the input quantities, while for the other options the input quantities are determined from the specified shape. However, for solution accuracy, the distribution of patch centers obtained with generally square patches has been found to be desirable.

**5.2.8.2 Patch Modeling of Surfaces.** NEC includes an option for modeling conducting surfaces with surface patches. This formulation uses the Magnetic Field Integral Equation (MFIE) and is restricted to closed surfaces with non-vanishing enclosed volume. It is not applicable to a conducting plate or shell of zero thickness. In fact, any condition, such as a gap or finite conductivity, that would allow the field to reach the inside of the surface is not allowed with the MFIE. The model works very well for a shape such as a sphere. It can be used for structures with edges, such as a cube, but reasonably small and uniform patches should be used along the edge to maintain accuracy. Also, a wire antenna cannot be connected at an edge. Theoretically, the MFIE can be used for a thin box or cylinder, but the solution may become inaccurate due to the decreasing condition number of the matrix and the simple point matching and pulse current expansion used in the solution in NEC.

A conducting surface is modeled by means of multiple, small, flat surface patches corresponding to the segments used to model wires. The patches are chosen to completely cover the surface to be modeled, conforming as closely as possible to curved surfaces. The parameters defining a surface patch are the Cartesian coordinates of the patch center, the components of the outward directed unit normal vector, and the patch area.

When a wire is connected to a surface, the wire must end at the center of a patch, with identical coordinates used for the wire end and the patch center. The program then divides the patch into four equal patches about the wire end. The four new patches are ordinary patches like those input by the user except when the interactions between these patches and the lowest segment on the connected wire are computed. In this case, an interpolation function is applied to the four patches to represent the current from the wire onto the surface, and the function is numerically integrated over the patches. Thus, the shape of the patch is significant in this case. The user should try to choose patches so that those with wires connected are approximately square. The connected wire is not required to be normal to the patch, but cannot lie in the plane of the patch. Only a single wire can connect to a given patch, and a segment can have a patch connection on only one of its ends. Also, a wire can never connect to a patch formed by subdividing another patch for a previous connection.

As with wire modeling, patch size measured in wavelengths is very important for accurate results. A minimum of about 25 patches should be used per square wavelength of surface area, with the maximum size for an individual patch being about 0.04 wavelength. Large patches may be used on large, smooth surfaces, while smaller patches are needed in areas of small radius of curvature, both for geometrical modeling accuracy and for accuracy of the integral equation solution. In the case of a square edge, a precise local representation cannot be included. However, smaller patches in the vicinity of the edge can lead to more accurate results since the current magnitude may vary rapidly in this region. Since connection of a wire to a patch causes the patch to be divided into four smaller patches, a larger patch may be input in anticipation of the subdivision.

While patch shape is not input to the program, very long narrow patches should be avoided when subdividing the surface. This point is illustrated in the NEC 4.0 User's Manual (Burke, 1992) for the calculation of the bistatic scattering cross section of a sphere.

In general, the use of surface patches is restricted to modeling voluminous bodies. The surface modeled must be closed since the patches only model the side of the surface from which their normals are directed outward. If a somewhat thin body, such as a box with one narrow dimension, is modeled with patches, the narrow sides (edges) must be modeled, as well as the broad surfaces. Furthermore, the parallel surfaces on opposite sides cannot be too close together, or severe numerical errors may occur.

### 5.2.9 Multiple Patch Quadrangle Surface (SM, SC) Window

This window covers a quadrangle with surface patches. Table 9 defines the Multiple Patch Quadradrangle Window parameters. See pages 39-43 of the NEC 4.0 User's Manual (Burke, 1992) for further information.

**Table 9**. Multiple Patch Quadrangle Surface (SM, SC) Window parameters.

| Parameter | Definition |
|---|---|
| Node of Corner 1 | Node of Corner 1 quadrangle |
| Node of Corner 2 | Node of Corner 2 quadrangle |
| Node of Corner 3 | Node of Corner 3 quadrangle |
| Number of Patches Corner 1 to 2 | Number of patches from Corner 1 to Corner 2 |
| Number of Patches Corner 2 to 3 | Number of patches from Corner 2 to Corner 3 |

**5.2.9.1 Additional Information.** Intrinsic diagnostics check that all nodes are one or greater.

In NEC 4.0, the quadrangle must be a rectangular region, and Corner 4 has no meaning. The direction of the outward normals of the patches is determined by the ordering of Corners 1, 2, and 3 and the right-hand rule.

### 5.2.10 Transformations (GM) Window

This window translates or rotates a structure with respect to the coordinate system or generates new structures translated or rotated from the original. Table 10 defines the Transformations Window parameters. See pages 30-31 of the NEC 4.0 User's Manual (Burke, 1992) for further information.

**Table 10**. Transformations (GM) Window parameters.

| Parameter | Definition |
|---|---|
| Tag Increment | Tag number increment |
| X Rotation | Angle or rotation about the x-axis in degrees |
| Y Rotation | Angle of rotation about the y-axis in degrees |
| Z Rotation | Angle of rotation about the z-axis in degrees |
| X Shift | X direction shift of structure |

**Table 10**. Transformations (GM) Window parameters. (Continued)

| Parameter | Definition |
|---|---|
| Y Shift | Y direction sift of structure |
| Z Shift | Z direction shift of structure |
| Number of New Structures | Number of new structures to be generated |

**5.2.10.1 Additional Information.** Intrinsic diagnostics check that all Number of New Structures is an integer greater than zero.

If Number of New Structures is zero, the structure is moved by the specified rotation and translation, leaving nothing in the original location. If the Number of New Structures is greater than zero, the original structure remains fixed. New structures are formed, each shifted from the previous one by the requested transformation.

The Tag Increment is used when new structures are generated (Number of New Structures greater than zero) to avoid duplication of tag numbers. Tag numbers of the segments in each new copy of the structure are incremented by Tag Increment from the tag on the previous copy or original. Tags of segments that are generated from segments having no tags (tag equal to zero) are not incremented. Generally, Tag Increment will be greater than or equal to the largest tag number used on the original structure to avoid duplication of tags.

The result of a transformation depends on the order in which the rotations and translation are applied. The order used is first rotation about the x-axis, then rotation about the y-axis, then rotation about the z axis, and finally, translation by X Shift, Y Shift, and then Z Shift. All operations refer to the fixed coordinate system axes. If a different order is desired, separate GM commands in the NEC 4.0 data set may be used.

### 5.2.11 Rotations (GR) Window

This window reproduces a structure while rotating about the z-axis to form a complete cylindrical array, and to set flags so that symmetry is utilized in the solution. Table 11 defines the Rotations Window parameters. See pages 32-33 of the NEC 4.0 User's Manual (Burke, 1992) for further information.

**Table 11**. Rotations (GR) Window parameters.

| Parameter | Definition |
|---|---|
| Tag Increment | Tag number increment |
| Number in Array | Total number of times that structure is to occur in the cylindrical array |

**5.2.11.1 Additional Information.** Intrinsic diagnostics check that Number in Array is an integer greater than zero.

The Tag Increment is used to avoid duplication of tag numbers in the reproduced structures. In forming a new structure for the array, all valid tags on the previous copy or original structure are incremented by Tag Increment. Tags equal to zero are not incremented.

Rotations should never be used when there are segments on the z-axis or when crossing the z-axis, since overlapping segments would result.

In NEC 4.0, the GR command sets flags so that the program makes use of cylindrical symmetry in solving for the currents. If a structure modeled with N segments has M sections in cylindrical symmetry (formed by a GR command with Number in Array equal to M), the number of complex numbers in matrix storage and the proportionality factors for the time to fill and factor the matrix are as shown in table 12.

**Table 12.** NEC 4.0 use of rotations.

| Cylindrical Symmetry | Matrix Storage | Fill Time | Factor Time |
|---|---|---|---|
| No Symmetry | $N^2$ | $N^2$ | $N^3$ |
| M Symmetrical Sections | $N^2/M$ | $N^2/M$ | $N^3/M$ |

The matrix factor time represents the optimum for a large matrix factored in core. Generally, somewhat longer times will be observed.

If the structure is added to or modified after the GR command so that cylindrical symmetry is destroyed, NEC 4.0 must be reset to a no symmetry condition. In most cases, the program is set by the geometry routines for the existing symmetry.

A GX or GR command for NEC 4.0 data input will destroy all previously established symmetry while establishing a new symmetric pattern.

If a structure is rotated about either the x- or y-axis by use of a GM command, and a ground plane is specified, all symmetry will be destroyed. Rotation about the z-axis or translation will not affect symmetry. If a ground is not specified, symmetry will be unaffected by any rotation or translation by a GM command, unless the Number of New Structures on the Transformations is greater than zero.

Symmetry will also be destroyed if lumped loads are placed on the structure in an unsymmetric manner. In this case, NEC 4.0 does not automatically set to a no symmetry condition. In the NEC 4.0 input data set, a command must follow the GX command to reset the no symmetry condition. A GW command can be used with zero Number of Segments. The Radius, however, must be greater than zero.

Placement of non-radiating networks or sources does not affect symmetry. When it is necessary to place an unsymmetrical load on an otherwise symmetric structure, symmetry can still be used in the solution if the load is introduced as a non-radiating network having appropriate parameters.

Rotations produce the same effect on the structure as the Transformations if the Number in Array is equal to the Number of New Structures + 1, and if the Z Rotation is equal to 360/(Number of New Structures + 1) degrees. However, if Transformations is used, the program will not be set to take advantage of symmetry.

### 5.2.12 Reflections (GX) Window

This window forms structures having planes of symmetry by reflecting part of the structure in the coordinate planes, and sets flags so that symmetry is used in the solution. Table 13 defines the

Reflections Window parameters. See pages 36-38 of NEC 4.0 User's Manual (Burke, 1992) for further information.

**Table 13**. Reflections (GX) Window parameters.

| Parameters | Definition |
|---|---|
| Tag Increment | Tag number increment |

**5.2.12.1 Additional Information.** Toggle buttons are available to choose axes of rotation. If the x option is chosen, the structure is reflected along the x-axis in the y-z plane. If the y option is chosen, the structure is reflected along the y-axis in the x-z plane. If the z option is chosen, the structure is reflected along the z-axis in the x-y plane.

Any combination of reflections along the x, y, and z axes may be used. For example, a problem with x reflection, no y reflection, and z reflection will cause reflection along the axes x and z, resulting in 4 times the original Number of Segments. A problem with reflection along axes x, y, and z results in 8 times the original Number of Segments. When combinations of reflections are requested, the reflections are done in reverse alphabetical order. For example, a structure is generated in a single octant of space. For a problem with reflections along axes x, y, and z, the structure is first reflected along the z-axis. The structure and its image are then reflected along the y-axis. Finally, these four copies are reflected along the x-axis to fill all octants. This order determines the position of a segment in the sequence.

The Tag Increment is used to avoid duplication of Tag numbers in the image segments. All valid tags on the original structure are incremented by Tag Increment on the image. When combinations of reflections are employed, the Tag Increment is doubled after each reflection. Thus, a Tag Increment greater than or equal to the largest tag on the original structure will ensure that no duplicate tags are generated.

Reflections should never be used when there are segments located in the plane about which reflection would take place or when crossing this plane. The image segments would then coincide with or intersect the original segments, and such overlapping segments are not allowed. However, segments may end on the reflection plane, and will connect to their images.

When a structure having plane symmetry is formed using Reflections, the NEC 4.0 program will make use of the symmetry to simplify solution for the currents. The number of complex numbers in matrix storage and the proportionality factors for matrix fill time and matrix factor time for a structure modeled by N segments are shown in table 14.

**Table 14**. NEC 4.0 use of symmetry.

| No. of Planes of Symmetry | Matrix Storage | Fill Time | Factor Time |
|---|---|---|---|
| 0 | $N^2$ | $N^2$ | $N^3$ |
| 1 | $N^2/2$ | $N^2/2$ | $N^3/2$ |
| 2 | $N^2/4$ | $N^2/4$ | $N^3/4$ |
| 3 | $N^2/8$ | $N^2/8$ | $N^3/8$ |

The matrix factor time represents the optimum for a large matrix factored in core. Generally, somewhat longer times will be observed.

In NEC 4.0, if the structure is added to or modified after Reflection in such a way that symmetry is destroyed, NEC 4.0 must be reset to a no symmetry condition. In most cases, the program is set by the geometry routines for the existing symmetry. Operations that automatically reset the symmetry conditions are as follows:

1. If a ground plane is specified, symmetry about a plane parallel to the x-y plane will be destroyed. Symmetry about other planes will be used, however.
2. If a structure is rotated about either the x- or y-axis by use of Transformations and a ground plane is specified, all symmetry will be destroyed. Rotation about the z-axis or translation will not affect symmetry. If a ground is not specified, rotation or translation will have no effect on symmetry conditions unless the Number of New Structures using Transformations is greater than zero.
3. Symmetry will also be destroyed if lumped loads are placed on the structure in an unsymmetric manner. In this case, NEC 4.0 does not automatically set to a no symmetry condition. In the NEC 4.0 input data set, a command must follow the GX command to reset the no symmetry condition. A GW command can be used with zero Number of Segments. The Radius, however, must be greater than zero.

Placement of non-radiating networks or sources does not reset the symmetry conditions. When it is necessary to place an unsymmetric load on an otherwise symmetric structure, symmetry can still be used in the solution if the load is introduced as a non-radiating network having appropriate parameters.

### 5.2.13 Spiral Ordering

This window reorders wires along a principal axis. The user can spiral along the positive x-axis, negative x-axis, positive y-axis, negative y-axis, positive z-axis, or negative z-axis. An axis should be chosen that is along the greatest length of the model. This can considerably reduce the solution time if an axis is chosen along the model's greatest length. This is a function of the matrix solution routine used in NEC-MoM.

### 5.2.14 CAD Interface

This option allows the user to load an AutoCad "*.dxf " file directly into the NEEDS Workstation. Only AutoCad descriptions consistent with the wire gridding of a structure will be interpreted into the NEEDS Workstation.

### 5.2.15 Edit Card Order

This option allows the user to order the geometry cards in a user-defined order.

The NEEDS system initially orders the geometry cards according to the card type. The ordering of the geometry card types is as follows:

1. Straight wire cards
2. Tapered wire cards

3. Catenary wire cards
4. Wire arc cards
5. Helix and spiral cards
6. Surfaces patch cards
7. Multiple patch quadrangle cards
8. Transformation cards
9. Reflection cards
10. Rotation cards

Within each card type, the cards are listed in order of their order in the given dialogue window list.

As displayed in figure 3, this option allows the user to only move transformation (GM), reflection (GX), and rotation (GR) cards. The user can choose any of these cards, cut, and paste. The card is pasted before the selected position. The user cannot close this window while a card has been cut and not pasted. This Order option will save the user-specified order of geometry cards when OK or Apply is selected.

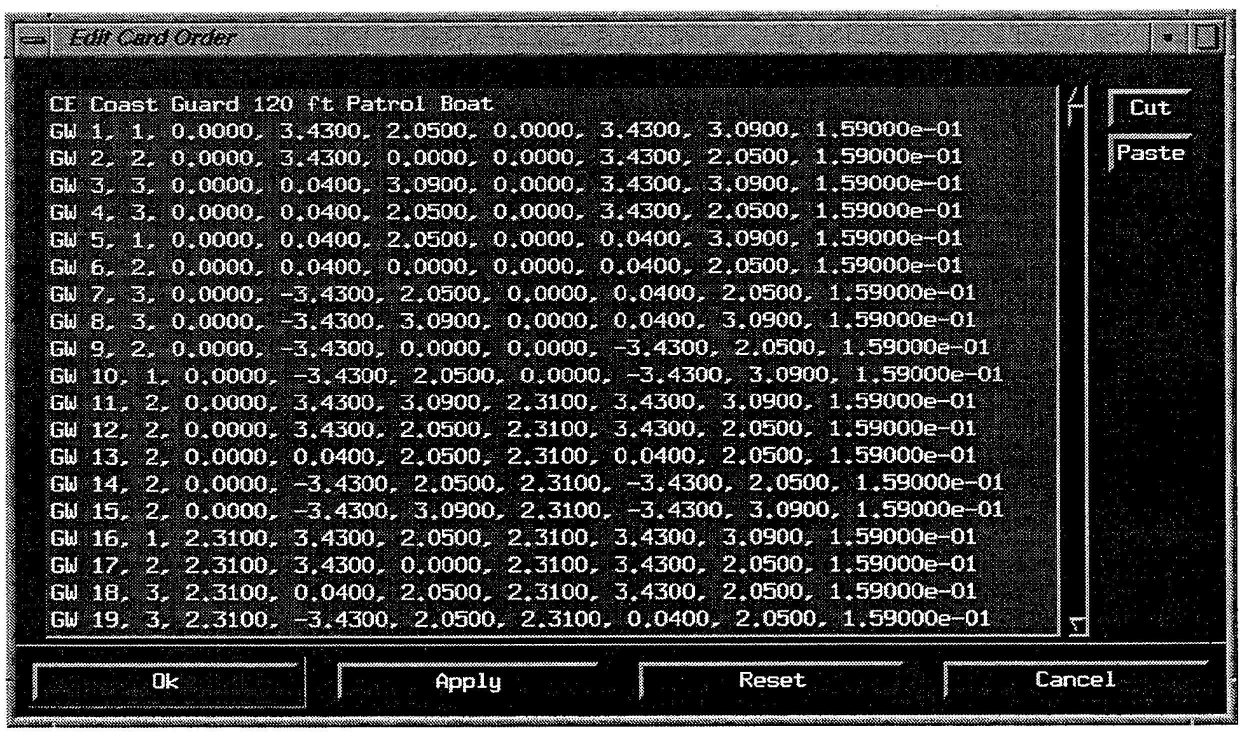


**Figure 3.** Geometry Description – Edit Card Order.

A user can continue to edit and modify the geometry. The Order option will continue to try to maintain the user reorientation of the transformation (GM), reflection (GX), and rotation (GR) cards within these geometry changes.

## 5.3 EDIT CONTROL CARDS

As displayed in figure 4, this window generates the control cards for the NEC-MoM input data set. Control cards are used to provide the electrical and solution descriptions for the given problem. The ordering of these control cards is important in the problem description.

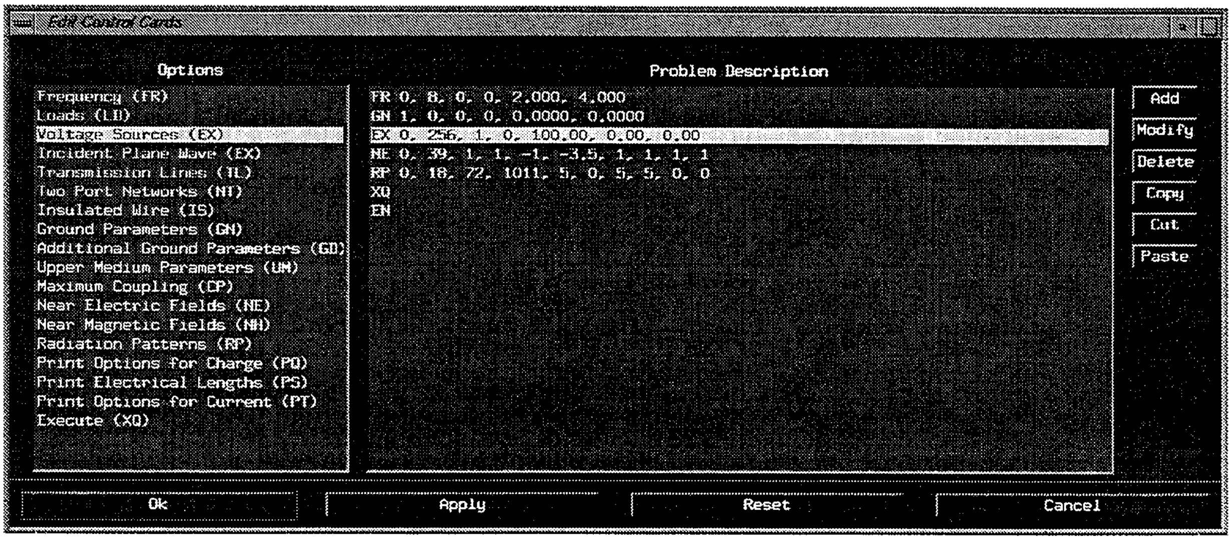


**Figure 4.** Edit Control Description.

Two list boxes are displayed. In the first list box are the options available for control cards. The second list box displays the problem description. The control card options include:

1. Frequency (FR)
2. Loads (LD)
3. Voltage sources (EX)
4. Incident plane wave (EX)
5. Transmission lines (TL)
6. Two-Port networks (NT)
7. Insulated wire (IS)
8. Ground parameters (GN)
9. Additional ground parameters (GD)
10. Upper medium parameters (UM)
11. Maximum coupling (CP)
12. Near electric field (NE)
13. Near magnetic field (NH)
14. Radiation patterns (RP)
15. Print options for charge (PQ)
16. Print electrical lengths (PS)

17. Print options for current (PT)

18. Execute (XQ)

Several push buttons are available on the right of this window to assist in the generation of the desired problem description.

**Add**—To add to the problem description, first highlight the desired option in the option list. Next, highlight an entry in the problem description list before the desired option is to be added. When the Add button is activated, a window will appear for the user to specify this additional control card.

**Modify**—To modify an entry in the problem description list, highlight the desired entry in the problem description list. When the Modify button is activated, a window will appear for the user to modify the desired control card.

**Delete**—To delete an entry in the problem description list, highlight the desired entry in the problem description list. When the Delete button is activated, the entry will be deleted.

**Copy**—To copy entries in the problem description, highlight the desired entries in the problem description list. When the Copy button is activated, these entries are available for Paste.

**Cut**—To cut entries in the problem description, highlight the desired entries in the problem description list. When the Cut button is activated, these entries are deleted from the list and are available for Paste.

**Paste**—To paste entries, Copy or Cut must have been used previously. When the Paste button is activated, the entries from Copy or Cut are pasted before the highlighted entry in the problem description list.

### 5.3.1 Frequency (FR) Window

This window specifies the frequency. Table 15 defines the Frequency Window parameters. See page 52 of the NEC 4.0 User's Manual (Burke, 1992) for further information.

**Table 15.** Frequency (FR) Window parameters.

| Parameter | Definition |
|---|---|
| Type | Determines the type of frequency stepping that is used |
| 0 | Linear stepping |
| 1 | Multiplicative stepping |
| Lowest Frequency | Frequency or starting frequency in a range |
| Frequency Step | Frequency stepping increment. If the frequency stepping is linear, this quantity is added to the initial frequency (number of steps – 1). Otherwise, this is the multiplication factor |
| Number of Steps | Number of frequency steps |

**5.3.1.1 Additional Information.** The options for the Frequency Units list box include kHz, MHz, and GHz.

Intrinsic diagnostics check that the Lowest Frequency is greater than zero with a default of 299.8 MHz, and the Number of Steps is an integer greater than zero.

If a FR command does not appear in the NEC 4.0 input data deck, a single frequency of 299.8 MHz is used. Since the wavelength at 299.8 MHz is 1 meter, the units for the geometry are then equivalent to wavelengths. In the NEC 4.00 input data set, Frequency commands may not be grouped together. If they are, only the information on the last FR command before execution will be used. After a frequency loop for Type greater than 1 has been completed, it will not be repeated for a second execution request. The FR command must be entered again to repeat the loop.

### 5.3.2 Loads (LD) Window

This window specifies the impedance loading on one segment or a number of segments. Series and parallel RLC circuits can be generated. In addition, a finite conductivity and permeability can be specified for segments. Table 16 defines the Loads Window parameters. Table 17 describes input for various load types. See pages 59-61 of the NEC 4.0 User's Manual (Burke, 1992) for further information.

**Table 16**. Loads (LD) Window parameters.

| Parameter | Definition |
|---|---|
| Type | Determines the type of loading that is used |
| 1 | Short all loads (used to nullify previous loads) |
| 0 | Series RLC; input in ohms, henries, farads |
| 1 | Parallel RLC; input in ohms, henries, farads |
| 2 | Series RLC; input in ohms/meter, henries/meter, farads/meter |
| 3 | Parallel RLC; input ohms/meter, henries/meter, farads/meter |
| 4 | Impedance; input resistance and reactance in ohms |
| 5 | Wire conductivity, mhos/meter |
| Tag | Identifies the wire sections to be loaded by their Tag numbers. The next two parameters can be used to further specify particular segments with this Tag number; Zero here implies that absolute segment numbers are being used as the next two parameters to identify segments; If the next two parameters are zero, all segments with this Tag number are loaded |
| Begin segment | First segment among those segments having the above Tag to which loading is to be applied |
| End segment | Last segment among those segments having the above Tag to which loading is to be applied; This parameter must be greater than or equal to the previous parameter, Begin Segment |

**Table 17**. Input for various load types.

| Load Type | Input |
|---|---|
| 0 | Series RLC: RESISTANCE - Resistance in ohms; INDUCTANCE - Inductance in henries; CAPACITANCE - Capacitance in farads; if none, enter zero |
| 1 | Parallel RLC: input the same as series. If the inductor is absent, enter zero for INDUCTOR |

**Table 17.** Input for various load types. (Continued)

| Load Type | Input |
|---|---|
| 2 | Series RLC with parameters per unit length: RESISTANCE - Resistance in ohms/m; INDUCTANCE - Inductance in henries/m |
| 3 | Parallel RLC, with parameters per unit length: RESISTANCE - Resistance in ohms/m; INDUCTANCE - Inductance in henries/m; if none enter zero, CAPACITANCE - Capacitance in farads/m |
| 4 | Fixed impedance: RESISTANCE - Resistance in ohms; INDUCTANCE - Reactance in ohms |
| 5 | Finitely conducting round wire: RESISTANCE - Bulk conductivity of metal in mhos/m; INDUCTANCE - relative permeability of the metal; loading commands can be input in groups to achieve a desired structure loading; the maximum number of loading commands in a group is determined by dimensions in the program; the limit in NEC 4.0 is presently 30 |

**5.3.2.1 Additional Information.** If a portion of a wire is loaded more than once by a group of loading commands, the loads are assumed to be in series (impedances added), and a message in NEC 4.0 is printed in the output, alerting the user to this fact.

When resistance and reactance are input (Load Type = 4), the impedance does not automatically scale with frequency.

Since loading modifies the interaction matrix, it will affect the conditions of plane or cylindrical symmetry of a structure. If a structure is geometrically symmetric and each symmetric section is to receive identical loading, then symmetry may be used in the solution. NEC 4.0 is set to utilize symmetry during geometry input by inputting the data for one symmetric section and completing the structure with a rotation GR or reflection GX command. If symmetry is used, the loading on only the first symmetric section is input on load LD commands. The same loading will be assumed on the other sections. Loading should not be specified for portions of wires beyond the first section when symmetry is used. If the sections are not identically loaded, then the geometry must be set to a no symmetry condition to permit independent loading of segments in different sections.

### 5.3.3 Voltage Sources (EX) Window

This window specifies the voltage source excitation for the structure. Table describes the parameters for the Voltage Sources Window. See pages 48-51 of the NEC 4.0 User's Manual (Burke, 1992) for further information.

**Table 18.** Voltage Sources (EX) Window parameters.

| Parameter | Definition |
|---|---|
| Type 0 | Voltage source (applied E-field source) |
| Type 5 | Voltage source (bicone source model) |
| Tag | Identifies by tag the wire(s) with voltage source |
| Format 1 | Impedances are collected over a frequency loop; The impedances will be printed in ohms and also normalized by either the maximum value (Normal = 0) or a factor specified by the Normal |

**Table 18**. Voltage Sources (EX) Window parameters. (Continued)

| Parameters | Definition |
|---|---|
| Segment | Number of the source segment in the set of segments having the Tag number; If Tag is zero, the Segment is the absolute segment number of the source segment |
| Magnitude | Magnitude of the source voltage in volts |
| Phase | Phase of the source voltage in degrees |
| Normal | Normalization factor for impedance when Format = 1 |

**5.3.3.1 Additional Information.** Intrinsic diagnostics check that the Magnitude is greater than zero.

The NEEDS system is unique in that a unique Tag number must be specified for each source. It is not possible to have unique sources on a wire with the same Tag number. This uniqueness is important to the display of the results.

The applied E-field voltage source is located on the segment specified by Tag and Distance.

The bicone voltage source is located at the first end of the specified segment, at the junction with the previous segment. This junction must be a simple two-segment junction with the segments collinear and with equal radii. The bicone source is not accurate unless the wire is very thin and the segment-to-radius ratio of the segment is reasonably large. The applied field source should be used for most applications.

A bicone source may lie in a symmetry plane at the junction between segments. An applied field source cannot lie in a symmetry plane, since a segment cannot cross a symmetry plane. A source centered on a symmetry plane can be modeled with the applied field source by exciting two segments on opposite sides of the plane, each with half of the total source voltage. The sign of each voltage source must take into account the opposing reference directions of the segments if one segment was generated by reflecting the other.

An applied field voltage source specified on a segment that has been loaded is connected in series with the load. An applied field source on the same segment as a network or transmission line is connected in parallel with the network or transmission line port. For a transmission line, the source is in parallel with both the line and any shunt load specified using Transmission Lines. Bicone voltage sources should not be used in combination with loads or network connections.

In NEC 4.0, several excitation EX commands can be grouped together to specify multiple sources of excitation. Normally, one or more voltage sources will be used on a transmitting antenna, and a single incident wave with a range of angles will be defined for receiving antennas or scatterers. If necessary, voltage sources and one or more incident plane waves may be combined. When mixed source types are used, the last source in the group of EX commands will determine the output format. If the last EX command specifies a voltage source, the output will show source parameters (input impedance and power) and antenna gains. These values will be altered by any incident plane waves as if by interference in a measurement situation. If the last source specified is an incident plane wave, the voltage source parameters will not be printed, and radiation patterns will show scattering cross sections.

**5.3.3.2 Voltage Source Description.** Modeling voltage sources is probably the most critical step in the moment-method analysis of wire antennas, since errors are directly reflected in the computed input admittance, and hence, in the gain and other related quantities. NEC 4.0 offers two models for voltage sources on wires: the applied field source and the bicone source.

In the applied field source model for a voltage, $V_i$, on segment, i, the electric field at the match point on segment, i, is set to $E_i = V_i$ / (source segment length). The segments on either side of the source segment should have the same segment length. When this rule is followed, the electric field along the wire will be found to have the prescribed value at the center of the source segment, remain approximately constant over the segment, and drop to small values beyond the region of the segment ends. When multiple wires are connected to one end of the source segment, the length of each segment at the junction should be made equal to that of the source segment, if possible. However, it appears to be less important to maintain equal segment lengths across a junction than on a continuous wire.

The field distribution over the source region can be checked by computing electric fields along the wire surface. The field distribution should be roughly rectangular on thin wires. With larger wire radius, the distribution will be more rounded since the field cannot change significantly over a distance much less than the wire radius. However, the important condition is that the line integral of the field across the source region should be equal to the source voltage. This condition is usually satisfied with the applied field source over a wide range of segment radii and lengths.

The other voltage source model offered in NEC 4.0 is the bicone source. In this model, the voltage is introduced at the junction between segments rather than on a segment by forcing a discontinuity in the charge density in the current expansion. The source voltage is related to the discontinuity in charge density through the model of a biconical transmission line. The segments on each side of a bicone voltage source should be collinear and should have the same length and radius.

The motivation behind the bicone source was to obtain a more localized distribution of the source field. The field distribution is localized in the junction region if the wire radius is sufficiently small. However, the field becomes more distributed with a larger wire radius. More important, the condition relating the source voltage to the charge distribution is not accurate for a large wire radius. Hence the bicone source model should only be used with very thin wires, and then, only with caution. It yields reasonably accurate input impedances on a dipole when length equals 0.5 wavelength and the thickness parameter (W = 2 ln ≡ natural log (length/radius)) is greater than about 15. However, the model also fails with decreasing segment-to-length ratio. Hence, it is recommended that the applied field source model be used in most cases.

### 5.3.4 Incident Plane Waves (EX) Window

This window specifies the incident plane wave excitation for the structure. Table 19 defines Incident Plane Waves Window parameters. See pages 48-51 of the NEC 4.0 User's Manual (Burke, 1992) for further information.

**Table 19**. Incident Plane Waves (EX) Window parameters.

| Parameters | Definition |
|---|---|
| Type | |
| 1 | Plane wave, linear polarization |
| 2 | Plane wave, right-hand elliptic polarization |
| 3 | Plane wave, left-hand elliptic polarization |
| Lowest Theta | The angle theta (degrees) to the incident vector |
| Theta Step | Stepping increment for theta |
| Number of Theta Steps | Number of theta angles |
| Lowest Phi | The angle phi (degrees) to the incident vector |
| Phi Step | Stepping increment for phi |
| Number of Phi Steps | Number of phi angles |
| Polarization Angle | The polarization angle between the theta unit vector and the incident electric field; For elliptical polarization, the Polarization Angle specifies the major ellipse angle for the electric field vector |
| Polarization Ratio | Ratio of minor to major axis for elliptic polarization |
| Magnitude of Electric Field | Magnitude of Electric Field (along major axis for elliptic polarization); The default is 1 volt/meter |

**5.3.4.1 Additional Information.** The intrinsic diagnostics check that the Number of Steps is an integer greater than zero.

In NEC 4.0, several excitation EX commands can be grouped together to specify multiple sources of excitation. Normally, one or more voltage sources will be used on a transmitting antenna, and a single incident wave with a range of angles, will be defined for receiving antennas or scatterers. If necessary, voltage sources and one or more incident plane waves and sources may be combined. When mixed source types are used, the last source in the group of EX commands will determine the output format. If the last EX command specifies a voltage source, the output will show source parameters (input impedance and power) and antenna gains. These values will be altered by any incident plane waves as if by interference in a measurement situation. If the last source specified is an incident plane wave, the voltage source parameters will not be printed, and radiation patterns will show scattering cross sections .

Looping over angles for an incident plane wave works only for the last EX command in a group. When looping over both theta and phi angles is specified for an incident plane wave, the theta angle changes more rapidly than the phi angle.

### 5.3.5 Transmission Lines (TL) Window

This window specifies a transmission line between any two wire segments on a structure. Characteristic impedance, length, and shunt admittance are the defining parameters. Table 20 defines the Transmission Lines Window parameters. See pages 76-77 of the NEC 4.0 User's Manual for further information.

**Table 20**. Transmission Lines (TL) Window parameters.

| Parameter | Definition |
|---|---|
| 1st Tag | Identifies by Tag wire with first end of the transmission line |
| 1st Segment | Number of the Segment to which the first end of the transmission line connects in the set of segments having the Tag number; If Tag is zero, the segment is the absolute segment number of the source segment; A value of -1 will cancel any networks or transmission line that have been previously defined |
| 2nd Tag | Identifies by Tag wire with second end of the transmission line |
| 2nd Segment | Number of the Segment to which the second end of the transmission line connects in the set of segments having the Tag number; If Tag is zero, the segment is the absolute segment number of the source segment. |
| Impedance | Characteristic impedance of the transmission line in ohms; A negative sign acts as a flag for generating a "crossed" transmission line with a 180-degree phase reversal relative to the reference directions of the segments |
| Length | Length of the transmission line in meters; If Length is entered as zero, a straight-line Distance is used between the specified connection points |
| 1st Real | Real part of the shunt admittance across End 1 |
| 1st Imaginary | Imaginary part of the shunt admittance across End 1 |
| 2nd Real | Real part of the shunt admittance across End 2 |
| 2nd Imaginary | Imaginary part of the shunt admittance across End 2 |

**5.3.5.1 Additional Information.** In a NEC 4.0 input data set, several TL commands may be combined to specify transmission lines on a structure. Network NT and TL commands may be intermixed in a group, but all must occur together, with no other commands separating them. When the first NT or TL command is read following a command other than NT or TL, all previous network and transmission line data are destroyed. Hence, if a set of transmission line data is to be modified, all transmission lines and networks must be entered again in the modified form. Dimensions in the NEC 4.0 program limit the number of TL commands that can be used.

One or more transmission lines or network ports can connect to any given segment. Multiple transmission lines and network ports connected to a segment are connected in parallel.

If a transmission line is connected to a segment that also has an impedance load, the load is on the wire in series with the transmission line connection(s).

A voltage source specified on the same segment as a transmission line is connected in parallel with the transmission line, and in series with any load. A shunt load specified by transmission lines will be across the voltage source.

NT and TL commands do not affect the interaction matrix or symmetry conditions in the NEC 4.0 solution.

Sometimes it is necessary to have a transmission line with one end free from the structure, but shorted, or to have several transmission lines connected in parallel at a point separate from the wire structure. Such configurations can be obtained with transmission lines by including very short, isolated segments in the model as connection points for the ends of the transmission lines. Ordinarily, single isolated segments should not be used since the solution for current will not be accurate. However, if the segment length is on the order of 0.0001 wavelength or less, the current on the segment will be negligible. The segments equate the voltages and currents on the connected transmission lines or network ports.

### 5.3.6 Two-Port Networks (NT) Window

This window specifies a two-port, non-radiating network connected between any two segments in the structure. The characteristics of the network are specified by its short-circuit admittance matrix parameters. Table 21 defines the parameters of the Two-Port Networks Window. See pages 66-68 of the NEC 4.0 User's Manual (Burke, 1992) for further information.

**Table 21**. Two-Port Networks Window parameters.

| Parameter | Definition |
|---|---|
| Tag 1 | Identifies by Tag wire with port one of the network |
| Segment 1 | Number of the Segment to which port one of the network is connected in the set of segments having the Tag number; If Tag is zero, the segment is the absolute segment number of the port one segment; A value of -1 will cancel any networks or transmission lines that have been previously defined. |
| Tag 2 | Identifies by Tag wire with second port of the network |
| Segment 2 | Number of the Segment to which port one of the network is connected in the set of segments having the Tag number; If Tag is zero, the segment is the absolute segment number of the port one segment; A value of -1 will cancel any networks or transmission lines that have been previously defined |
| Real Y11 | Real part of Y11 in mhos |
| Imaginary Y11 | Imaginary part of Y11 in mhos |
| Real Y12 | Real part of Y12 in mhos |
| Imaginary Y12 | Imaginary part of Y12 in mhos |
| Real Y22 | Real part of Y22 in mhos |
| Imaginary Y22 | Imaginary part of Y22 in mhos |

**5.3.6.1 Additional Information.** The six parameters that specify the real and imaginary parts of the three short-circuit admittance matrix elements are: Y11, Y12, and Y22. The admittance matrix is symmetric, so it is unnecessary to specify Y21. The sign of Y12 must be determined for the reference directions for current into the positive side of each port.

In a NEC 4.0 input data set, several network NT commands may be combined to specify networks on a structure. NT and TL commands may be intermixed in a group, but all must occur together, with no other commands separating them. When the first NT or TL command is read following a command other than NT or TL, all previous network and transmission line data are destroyed. Hence, if a set of network data is to be modified, all network data must be entered again in the modified form. Dimensions in the program limit the number of networks that can be specified.

One or more network ports can connect to any given segment. Multiple network ports connected to a segment are connected in parallel.

If a network is connected to a segment that also has an impedance load, the load is on the wire in series with the network port.

A voltage source specified on the same segment as a network port is connected in parallel with the network port, and in series with any load.

NT commands can be used as an alternative to specify impedance loading on segments. While only fixed admittances can be specified in this way, the technique has the advantage that loads placed with a NT command do not change the structure interaction matrix. Hence, if unsymmetric loads are specified with NT commands, the code can still take advantage of structure symmetry in the solution procedure. Also, each time that loads entered with NT commands are changed, the code only needs to solve for the new currents. The interaction matrix does not need to be recomputed and factored as would be done if loads defined with the LD command were changed.

When defining network admittance parameters, it must be remembered that the reference direction for current is into the positive side of each port. The NEC 4.0 User's Manual (Burke, 1992) gives several examples of two-port networks.

Port 1 of a network can be connected to a segment to introduce a load of R ohms. Port 2 can be connected to any other segment, with no effect.

The net current transferred between ports 1 and 2 by a single wire with a resistance is zero, since the currents are balanced at each port.

An ideal transformer with zero loss cannot be defined since the short-circuit admittance parameters for it cannot be written. If a low-loss transformer is needed, resistance in the network can be reduced until the solution starts to become unstable. The minimum resistance will depend on the precision of the computer.

### 5.3.7 Insulated Wire (IS) Window

This window specifies an insulating sheath of dielectric or lossy material on a wire. Table 22 defines the Insulated Wire Window parameters. See pages 58 of the NEC 4.0 User's Manual (Burke, 1992) for further information.

**Table 22**. Insulated Wire (IS) Window parameters.

| Parameter | Definition |
|---|---|
| CANCEL | |
| 1 | Cancels previous sheath data |
| 2 | New data |
| Begin Segment | First segment among those segments having the above Tag to which an insulating sheath is to be applied; If Tag = 0, the segment is an absolute segment number; If both Tag and Begin Segment are zero, all segments will be insulated |
| End Segment | Last segment among those segments having the above Tag to which an insulating sheath is to be applied; If Tag = 0, the segment is an absolute segment number |
| Permittivity | Relative permittivity of the sheath material |
| Conductivity | Conductivity of the sheath material, mhos per meter |
| Radius | Radius of the sheath in meters; Radius must be greater than the wire radius |

**5.3.7.1 Additional Information.** In a NEC 4.0 input data set, if several IS commands are grouped together, their effects are combined. However, only a single sheath can be specified on a given segment. The maximum number of IS commands in a group is determined by dimensions in the NEC 4.0 program.

**5.3.7.2 Insulated Wires (NEC 4.0).** Segment lengths on insulated wires should be chosen relative to the effective electrical length of the wire. When the index of refraction of the sheath material is higher than that of the surrounding medium, the propagation constant along the wire will be greater than in the outer medium. However, for sheath thicknesses within the limits that can be handled by NEC 4.0, the difference should not be large. Hence, segment lengths can be chosen relative to the wavelength in the outer medium.

When the index of refraction of the sheath material is less than that of the surrounding medium, as it is for air insulation in water, the propagation constant on the wire can be much smaller than in the outer medium. The segments can then be much longer than on a bare wire in that medium. NEC 4.0 computes the ratio of the complex permittivity in the outer medium to that in the sheath material as

$$R_s = |(\varepsilon_1 - j\sigma_1)/(\varepsilon_2 - j\sigma_2)|,$$

where $\varepsilon_1$ and $\sigma_1$ are the relative permittivity and conductivity of the outer medium and $\varepsilon_2$ and $\sigma_2$ are those for the sheath material. If $R_s$ is greater than 4, the approximate wave number of current propagating on the wire is computed using the transmission line formula. The wave number, $k_s$, is used in the sinusoidal current expansion in NEC 4.0. Hence, segment lengths can be chosen relative to the wavelength $\lambda_s = 2\,\pi/k_s$. As for a wire in an infinite medium, the segment length should be less than about 0.1 wavelength. In the NEC 4.0 input data set, the print (PS) command (section 5.4.5) will cause NEC 4.0 to print a table of segment lengths relative to wavelength. If PS is followed by EN, the user can check the electrical lengths of segments without executing the remainder of the solution.

The sheath radius is also limited relative to the wavelength in the surrounding medium. For wave number, $k_1$, in the outer medium and sheath radius, b, the limit is about $|k_1 b| < 0.15$. There does not appear to be a limit on the ratio of sheath radius to wire radius.

The NEC 4.0 model appears to be less accurate for a discontinuous sheath in air than when the sheath covers all of the wire. This was seen in a check of the power balance of input power and radiated power. The NEC 4.0 code has not been checked for an insulated wire with grounded ends in the earth, so such a situation should be approached with caution. It would probably be safest to use grounding stubs that are 0.25 wavelength long in the medium, so that a charge minimum occurs at the end of the sheath.

### 5.3.8 Ground Parameters (GN) Window

This window specifies the relative dielectric constant and conductivity of the ground in the vicinity of the antenna. In addition, a second set of ground parameters for a second medium can be specified, or a radial wire ground screen can be added using a reflection coefficient approximation. Table 23 defines the Ground Parameters Window parameters. See pages 55-57 of the NEC 4.0 User's Manual (Burke, 1992) for further information.

**Table 23**. Ground Parameters (GN) Window parameters.

| Parameter | Definition |
|---|---|
| Ground Type | Ground type flag. The options are: Free Space; Finitely Conducting Ground, Reflection Coefficient Approximation; Perfectly Conducting Ground; and Finitely Conducting Ground, Sommerfeld/Asymptotic Method |
| **If Ground Type is Finitely Conducting, Reflection Coefficient Approximation** | |
| Number of Radial Wires | Number of radial wires in the ground screen approximation; If there is no ground screen, 0 must be entered |
| Dielectric | Relative dielectric constant for ground in the vicinity of the antenna |
| Conductivity | Conductivity in S/m of the ground; If Conductivity is input as a negative number, the imaginary part of the complex dielectric constant is set to Conductivity |
| **If Number of Radial Wires is greater than zero** | |
| Screen Radius | Radius of the screen in meters |
| Wire Radius | Radius of the screen wires in meters |
| **If Number of Radial Wires equals zero, second medium parameters beyond the primary ground plane can be specified; These parameters alter the far field patterns, but do not affect the antenna impedance or current distribution** | |
| Dielectric 2 | Relative dielectric constant of medium 2 |
| Conductivity 2 | Conductivity of medium 2 in S/m |
| Distance | Distance along the x-axis to the linear boundary (parallel to the y-axis) between the first and second media; For a circular boundary, the Additional Ground Parameters (GD) command must be used |

**Table 23.** Ground Parameters (GN) Window parameters. (Continued)

| Parameter | Definition |
|---|---|
| Height | Height in meters (positive or zero) by which the surface of medium 2 is below medium 1 |
| **If the Ground Type is Finitely Conducting Ground, Sommerfeld/Asymptotic Method,** | |
| File Name | Name of a file with a table of Sommerfeld-integral values for each frequency, as needed |

**5.3.8.1 Additional Information.** When the Ground Type is Finitely Conducting Ground, Reflection Coefficient Approximation, the RCA offers a fast, approximate solution for structures over ground. Its use should be limited to structures at least several tenths of a wavelength above the ground surface. It cannot be used to model long wire antennas over ground. Since surface wave is not included in this approximation, the field will go to zero as the path between source and evaluation points approaches grazing incidence to the ground. The time to fill the interaction matrix with the RCA is about twice that required for free space, due to computation of the field of each source's image.

When the Sommerfeld/Asymptotic ground model is used, NEC 4.0 requires a table of Sommerfeld integral values for the fields due to a source near ground. The Sommerfeld integral table is independent of the structure being modeled and depends only on the complex relative permittivity of the ground. Hence, it is independent of scaling and depends only on relative dielectric constant and the ratio conductivity to frequency. Since generating the values for the tables requires a moderate amount of computer time, it is advantageous to save the table in a file if other problems with the same ground parameters and frequency will be run. The Sommerfeld integral file for given ground parameters and frequency may be generated in advance of the NEC 4.0 run by running the program *SOMNEX*, or it will be generated by NEC 4.0 before continuing with the moment-method solution. When NEC 4.0 is run, a name for the Sommerfeld integral file can be specified by the user. If a file name is not specified, NEC 4.0 looks for the default file name "SOMS.NEC" for single precision or "SOMD.NEC" for double precision. The file is binary, so a single precision NEC can only read a single-precision file and a double-precision NEC can only read a double precision file. If a file with the user-specified name is not found, or if the file is found but has the wrong ground parameters, NEC 4.0 will compute the Sommerfeld integral table for use in the solution. It will also write the table on a file for later use, using the specified file name or the default name "SOMS.NEC". If **NOFILE** is entered in place of the file name, the file of Sommerfeld integral values will not be written.

If a data set requests the solution at multiple frequencies using the Sommerfeld ground model, NEC 4.0 will generate the Sommerfeld integral tables for each frequency, as needed. The tables will also be written to a sequence of files named "SOMS.NEC", "SOMS1.NEC", "SOMS2.NEC", . . . or with the same pattern using a file name entered on the GN command. NEC 4.0 also attempts to read files using this same naming sequence, so once a frequency loop has been completed, a subsequent data set or later NEC run using the same ground parameters and frequencies can read the files rather than recomputing the Sommerfeld integral tables. If a data set repeats the solution for a sequence of different ground parameters using multiple GN commands in a NEC 4.0 input data set, a similar sequence of Sommerfeld integral files can also be generated for later use. However, it is necessary to omit the file name and allow the default name to be used. Whenever a file name is specified by the user, that exact name will be used.

With the Sommerfeld/Asymptotic solution, the time to fill the interaction matrix will be about 6 to 8 times that for free space.

The radial wire ground screen approximation can be used only with the RCA since it is based on a modified reflection coefficient. The reflection coefficient at each point on the ground is computed from the surface impedance, which is the parallel combination of the radial wire screen and the ground impedance. The radial wire ground screen approximation neglects important effects seen with a real ground screen, but may be useful with some antennas over a radial wire screen. The impedance of the screen is zero at the center (x = 0 and y = 0), so the solution for a vertical monopole at this point will be the same as for the monopole on a perfectly conducting ground.

In NEC 4.0, the parameters for a second ground medium can be entered on the GN command as a convenience, but the usual command for defining these parameters is GD. The second medium affects the calculation of radiated fields but not antenna currents or near fields. However, if the second medium parameters are modified by entering a new GN command, the code will have to recompute the interaction matrix since it will be assumed that the primary ground parameters may have been changed. More information on the use of a second ground medium can be found in the following section.

### 5.3.9 Additional Ground Parameters (GD) Window

This window specifies the ground parameters of a second medium that is not in the immediate vicinity of the antenna. This command may only be used if a ground parameters GN command has also been entered. Table 24 defines the parameters of the Additional Ground Parameters Window. See pages 53-54 of the NEC 4.0 User's Manual (Burke, 1992) for further information.

**Table 24**. Additional Ground Parameters (GD) Window parameters.

| Parameter | Definition |
|---|---|
| Boundary type | Type of boundary |
| 1 | Linear boundary along x-axis at Boundary Distance |
| 2 | Circular boundary at radius of Boundary Distance |
| Dielectric | Relative dielectric constant of the second medium |
| Conductivity | Conductivity of the second medium in S/m |
| Boundary Distance | Distance in meters from the origin of the coordinate system to the boundary between media 1 and 2 |
| Boundary Height | Distance in meters (positive or zero) by which the surface of medium 2 is below medium 1 |

**5.3.9.1 Additional Information.** In computing the radiated field in a given direction, NEC 4.0 determines the point on the first or second medium where the ray from each segment or patch reflects, and uses the appropriate ground parameters and the height of the ground in computing the reflected ray. Diffraction from the cliff edge is not included.

When the ground wave is computed, the second medium parameters from a GD command have no effect. The surface wave can only be computed for an infinite flat ground with the primary ground parameters.

In NEC 4.0, the GD command can only be used in a data set where the GN command has been entered since GN is the only way to specify the ground parameters in the vicinity of the antenna.

Only one GD command is effective at a time. Multiple cliffs are not allowed.

The second medium parameters affect only the radiated field, and not the near fields or the calculation of currents. If the segments and patches extend out over the second medium, the currents will still be computed for the structure over the primary medium defined as the ground parameters. Hence, if the primary ground is perfectly conducting, and the GD command specifies a real ground, the currents will be computed for the structure over an infinite, perfectly conducting ground, and the radiated field will be computed for the ground parameters on the GD command.

If a linear boundary is needed, the parameters on the GD command can be entered on the GN command. However, each solution with a new GN command requires recalculation of the matrix, while changing the parameters on GD does not.

### 5.3.10 Upper Medium Parameters (UM) Window

This window specifies the relative permittivity and conductivity of an infinite medium or of the upper medium over a ground plane. Table 25 defines the Upper Medium Window parameters. See page 78 of the NEC 4.0 User's Manual (Burke, 1992) for further information.

**Table 25**. Upper Medium (UM) Window parameters.

| Parameter | Definition |
|---|---|
| Permittivity | Relative permittivity of the medium |
| Conductivity | Conductivity of the medium in S/m; If Conductivity is input as a negative number, the imaginary part of the relative dielectric constant is set to the Conductivity |

**5.3.10.1 Additional Information.** Parameters set by UM may affect the conditions for choosing segment lengths and patch sizes in the model.

UM cannot be used with the Sommerfeld/Asymptotic ground model.

### 5.3.11 Maximum Coupling Calculation (CP) Window

This window requests calculation of the maximum coupling between sources on two segments. Table 26 defines the Maximum Coupling Calculation Window parameters. See pages 46 of the NEC 4.0 User's Manual (Burke, 1992) for further information.

**Table 26**. Maximum Coupling Calculation (CP) Window parameters.

| Parameter | Definition |
|---|---|
| 1st Tag | Identifies wire by Tag for the first location of the coupling calculation |
| 1st Segment | Number of the First Segment for the first port in the coupling calculation, counting only segments having the 1st Tag; If the 1st Tag is zero, the segment is the absolute segment |

Table 26. Maximum Coupling Calculation (CP) Window parameters. (Continued)

| Parameter | Definition |
|---|---|
| 2nd Tag | Identifies wire by Tag for second location of the coupling calculation |
| 2nd Segment | Number of the Second Segment for the second port in the coupling calculation, counting only segments having the 1st Tag; If the 1st Tag is zero, the segment is the absolute segment. |

**5.3.11.1 Additional Information.** In NEC 4.0, when the CP command is read, it causes immediate calculation of the coupling between the two specified segments. Hence, the method-of-moments matrix will be evaluated and factored, if this has not already been done. The specified segments will then be excited one at a time, with the other segment short circuited to compute the self and mutual admittances. However, the currents resulting from this solution will not be printed. If a printout of the currents or radiation patterns is needed, the segments must be excited in a separate step with the specification of voltage.

### 5.3.12 Near Electric Field (NE) Window

This window requests calculation of near electric fields in the vicinity of the antenna. Table 27 defines the Near Electric Field Window parameters. See pages 62-63 of the NEC 4.0 User's Manual (Burke, 1992) for further information.

Table 27. Near Electric Field (NE) Window parameters.

| Parameter | Definition |
|---|---|
| Type | Selects the type of coordinate system for evaluation points; The field components will be printed in rectangular coordinates or spherical coordinates |
| 0 | Rectangular coordinates |
| 1 | Spherical coordinates |
| NRX | Number of points in the x or r direction |
| NRY | Number of points in the y or theta direction |
| NRZ | Number of points in the z or phi direction |
| XNR | Initial x or r coordinate in meters |
| YNR | Initial y coordinate in meters or theta coordinate in degrees |
| ZNR | Initial z coordinate in meters or phi coordinate in degrees |
| DXNR | Increment for x or r in meters |
| DYNR | Increment for y in meters or theta in degrees |
| DZNR | Increment for z in meters or phi in degrees |

**5.3.12.1 Additional Information.** When only one frequency is being used in the NEC 4.0 input data set, near field commands may be grouped together to calculate fields at points with various coordinate increments. In this case, each command encountered produces an immediate execution of the method-of-moments solution, and the results are printed. When automatic frequency stepping is used, only one electric or magnetic near-field command can be used for program control inside the frequency loop. Furthermore, the near-field command does not initiate an execution in this case. Execution will begin only after a subsequent radiation pattern command (section 5.4.4) or execution command (XQ) is read.

When a ground plane is modeled with the Sommerfeld/Asymptotic solution, the near magnetic field will be computed from a finite difference evaluation of using central differences. Hence, the time required for each magnetic field evaluation will be 6 times the time for a single electric field evaluation. Also, the evaluation of differences may magnify errors due to the table lookup for the electric field or due to transitions from table lookup to asymptotic approximations. These errors are most noticeable at very-low frequencies. The increment used for the differences is 0.001 of a wavelength in x, y, and z. Hence, the evaluation point should not be closer than 0.001 of a wavelength to any boundary, such as the ground surface.

When the reflection coefficient approximation (RCA) has been selected for the specification of ground (section 5.3.8), the near electric or magnetic field is computed directly using the reflection coefficient. However, the field at a distant point on the ground may be greatly underestimated with the RCA since the surface wave is not included.

### 5.3.13 Near Magnetic Field (NH) Window

This window requests calculation of near magnetic fields in the vicinity of the antenna. Table 28 defines the Near Magnetic Field Window parameters. See pages 64-65 of the NEC 4.0 User's Manual (Burke, 1992) for further information.

**Table 28**. Near Magnetic Field (NH) Window parameters.

| Parameter | Definition |
|---|---|
| Type | Selects the type of coordinate system for evaluation points |
| 0 | Rectangular coordinates |
| 1 | Spherical coordinates |
| NRX | Number of points in the x or r direction |
| NRY | Number of points in the y or theta direction |
| NRZ | Number of points in the z or phi direction |
| XNR | Initial x or r coordinate in meters |
| YNR | Initial y coordinate in meters or theta coordinate in degrees |
| ZNR | Initial z coordinate in meters or phi coordinate in degrees |
| DXNR | Increment for x or r in meters |
| DYNR | Increment for y in meters or theta in degrees |
| DZNR | Increment for z in meters or phi in degrees |

**5.3.13.1 Additional Information.** When only one frequency is being used in the NEC 4.0 input data set, near-field commands may be grouped together to calculate fields at points with various coordinate increments. In this case, each command encountered produces an immediate execution of the method-of-moments solution, and the results are printed. When automatic frequency stepping is being used, only one electric or magnetic near-field command can be used for program control inside the frequency loop. Furthermore, the near-field command does not initiate an execution in this case. Execution will begin only after a subsequent radiation pattern command (section 5.4.4) or execution command (XQ) is read.

When a ground plane is modeled with the Sommerfeld/Asymptotic solution, the near magnetic field will be computed from a finite difference evaluation of using central differences. Hence, the time required for each magnetic field evaluation will be 6 times the time for a single electric field evaluation. Also, the evaluation of differences may magnify errors due to the table lookup for the electric field or due to transitions from table lookup to asymptotic approximations. These errors are most noticeable at very low frequencies. The increment used for the differences is 0.001 of a wavelength in x, y, and z. Hence, the evaluation point should not be closer than 0.001 of a wavelength to any boundary, such as the ground surface.

When the reflection coefficient approximation has been selected for the specification of ground (section 5.3.8), the near electric or magnetic field is computed directly using the reflection coefficient. However, the field at a distant point on the ground may be greatly underestimated with the RCA since the surface wave is not included.

### 5.3.14 Radiation Patterns (RP) Window

This window requests the calculation of radiation patterns. Table 29 defines the Radiation Patterns Window parameters. See pages 73-75 of the NEC 4.0 User's Manual (Burke, 1992) for further information.

**Table 29**. Radiation Patterns (RP) Window parameters.

| Parameters | Definition |
|---|---|
| Mode | Selects the mode of the calculation for the radiated field |
| 0 | The space wave field is computed in spherical coordinates |
| 1 | The total ground wave is computed, including surface wave, in a cylindrical coordinate system |
| Number of Thetas | Number of values of theta at which the field is to be computed (number of values of z for Mode -1 |
| Number of Phis | Number of values of phi at which the field is to be computed |
| XNDA | This optional integer consists of four independent digits, each having a different function |
| X | Controls output format for antenna gain; If X = 0, then major-axis, minor-axis, and total gain are printed; If X = 1, then vertical, horizontal, and total gain are printed |
| N | Causes normalized gain for the specified field points to be printed after the standard gain and field strength output; The gain will be normalized to the value entered for Gain Normalization, or to the maximum gain, if zero; The component of gain that is normalized is determined by the value of N as follows: |
| 0 | For no normalized gain |
| 1 | Major axis gain normalized |
| 2 | Minor axis gain normalized |
| 3 | Vertical axis gain normalized |

**Table 29.** Radiation Patterns (RP) Window parameters. (Continued)

| Parameters | Definition |
|---|---|
| 4 | Horizontal axis gain normalized |
| 5 | Total gain normalized |
| D | Selects either power gain (D=0) or directive gain (D=1) for both the gain field value tables and for normalization; If the structure excitation is an incident plane wave, the quantities printed under the heading "GAIN" will actually be the scattering cross section and will not be affected by the value of D |
| A | Requests calculation of average power gain over the sector of space within the limits selected for theta and phi: |
| 0 | No average gain calculation |
| 1 | Average gain is computed |
| 2 | Average gain is computed, but printing of the individual gain and field values is suppressed |
| Initial Theta | Initial theta angle in degrees (z in meters if Mode = 1) |
| Initial Phi | Initial phi angle in degrees |
| Theta Increment | Stepping increment for theta in degrees (z in meters if Mode = 1) |
| Phi Increment | Stepping increment for phi in degrees |
| Radial Distance | Radial Distance (in meters) of the field point from the origin. If zero, the radiated field will have the factor If Type = 1, then distance represents the cylindrical coordinate r in meters and is not optional. |
| Gain Normalization | The Gain Normalization factor |

**5.3.14.1 Additional Information.** In a NEC 4.0 input data set, the RP command will initiate program execution, causing the interaction matrix to be computed and factored, and the structure currents to be computed if these operations have not already been performed. Hence, all required input parameters must be set before the RP command is read.

At a single frequency, any number of RP commands may occur in sequence so that different field point spacings may be used over different regions of space. If automatic frequency stepping is used, only one RP command will act within the frequency loop. Subsequent RP commands will calculate patterns at the final frequency only.

When both Number of Thetas and Number of Phis are greater than one, the angle theta (or z when Mode = 1) will be stepped faster than phi.

NEC 4.0 computes average gain by integrating the radiated power over a sector of space determined by the range of theta and phi. The power integrated in this sector is then divided by the solid angle of the sector and multiplied by $4\pi$. The result is the total power that would be radiated by the antenna if radiation into other sectors of space duplicated radiation in the integrated sector. This procedure is used to reduce the number of radiated field evaluations needed when the user can see due to symmetry that the radiation pattern will repeat over symmetric sections. For example, for a vertical dipole or monopole, only two cuts in theta with different values for phi are needed. The result for power radiated into 4 pi steradians is printed by NEC 4.0. If the antenna is over a ground plane with either finite or perfect conductivity, the radiation below the ground plane (theta > 90 degrees) is zero. Hence, the result obtained for radiated power into $4\pi$ steradians will be twice the actual power radiated when the sector integrated is only in the upper half space. The average gain computed for a lossless antenna should be 1.0 if the antenna is in free space, and 2.0 over perfectly conducting ground with the integration in the upper half space. Integrating the power in the far field gives the total radiated power in a variational form that is insensitive to small errors in the computed current distribution. Hence, the power obtained in this way should be more accurate than the input power computed at the source. The latter is sensitive to errors in the source voltage and current.

### 5.3.15 Print Options (PQ, PS, PT)

This window controls printing of charge on wires, electrical lengths of segments, and currents on wires. Table 30 defines the parameters of the Print Options Window parameters. See pages 70-72 of the NEC 4.0 User's Manual (Burke, 1992) for further information.

**Table 30**. Print Options (PQ, PS, PT) Window parameters.

| Parameter | Definition |
|---|---|
| Charge Densities | Print control flag for Charge Densities on wire segments |
| –1 | Suppress printing of Charge Densities |
| 0 | Print Charge Densities on the specified segments |
| Electrical Lengths | Prints a table of segment coordinates, length and radius relative to the effective wavelength for current propagating on the wire |
| Currents | Prints currents on wire segments; The options are: |
| –2 | All currents are printed |
| –1 | Suppress printing of all wire segment currents |
| 0 | Current printing will be limited to the segments specified |
| 1 | Currents are printed in a format designed for receiving patterns |
| 2 | Same as for 1 above; However, in addition, the current for one segment will be normalized to its maximum, and the normalized values along with the relative strength in dB will be printed in a table; If the currents for more than one segment are being printed, only currents from the last segment in the group appear in the normalized table. |
| 3 | Only normalized receiving pattern currents from one segment are printed |
| Wire Tag | Identifies wire by Tag for which current or charge will be printed |
| Begin Segment | Identifies first segment for which currents will be printed counting only segments with Tag. If Tag = 0, this Begin Segment is the absolute segment. If Begin Segment is zero, the charge density is printed for all segments |
| End Segment | Identifies last segment for which currents will be printed counting only segments with Tag. If Tag = 0, this End Segment is the absolute segment |

**5.3.15.1 Additional Information.** In NEC 4.0, the PS command prints the segment lengths and radii relative to the effective wavelength for current propagating on the wire. For ordinary wires in free space or in any medium, the wavelength is the wavelength in the medium. For an insulated wire in a dielectric or conducting medium, the wavelength is computed as $2\pi/k_s$, where $k_s$ is the wave number for current propagating on the wire, determined by the transmission line approximation for an insulated wire. The wavelength in the dielectric or conducting medium should also be used in determining the segment lengths and radii.

If a PS command is followed by the EN command, the table of electrical lengths can be obtained without executing the solution. Segment lengths can then be adjusted before solving for currents.

#### 5.3.16 Execute - XQ

# 6. EXECUTE

This command requests execution of the solution for current.

The submenu options for Execute include the following items.

1. Description Summary - Ctl+D
2. Diagnostics - Shf+D
3. NEC-MOM Execute - Ctl+X
4. NEC-MOM Run Status - Shf+X

The hot keys for accessing the specific options are also indicated. Each option is explained in the following sections.

## 6.1 DESCRIPTION SUMMARY

This option provides a short summary of the problem description terms of the geometry, electrical, and solution descriptions. This is useful as a diagnostic to determine if there are any obvious missing descriptions to the problem.

## 6.2 DIAGNOSTICS

This option evaluates the problem description against the modeling guidelines. Method-of-moments solutions to antenna problems are, at best, approximations. A set of modeling guidelines have been developed to aid the user in constructing a numerical model of an antenna. These guidelines agree with the assumptions of the formulation. With experience, a user may want to change these guidelines. However, the present experience is described in the following sections.

### 6.2.1 Wires

An overview of wire modeling is given in section 5.2.2. In addition, tables 31, 32, and 33 suggest the following guidelines for individual wires, wire junctions, and crossed wires, respectively.

**Table 31**. Wire modeling guidelines for individual wires.

| Wire | Guideline |
|---|---|
| Segment Length (wavelength) | Each wire should be subdivided into segments comparable to less than 0.1 wavelength; There is significant loss of accuracy if the segment is greater than 0.2 wavelength |
| Segment Length/Radius Ratio | The shortest permissible segment is usually determined by the wire radius; With the thin-wire assumption the ratio of Segment Length to Wire Radius should be maintained greater than 8. Some reasonable results can be obtained down to 2 |
| Radius (wavelengths) | The wires must be "thin" because the current is assumed to flow axially on the wire with no circumferential component; The wires are considered to fully satisfy the guidelines if they are thinner than 0.01 wavelength; If wires are fatter than wavelength / 30, the results may be in error |

**Table 32**. Wire modeling guidelines for wire junctions.

| Wire | Guideline |
|---|---|
| Segment Length Ratio | Wires making up a junction should not be too dissimilar; The ratio should be less than 2; Differences greater than 5 should be avoided |
| Radius Ratio | The ratio should be less than 10 |
| Special Wires (i.e., catenary, arcs, helix/spiral) | Evaluated against the same modeling guidelines as the straight wires |

**Table 33**. Wire modeling guidelines for crossed wires.

| Wire | Guideline |
|---|---|
| Number of Wire Radii | Defines the distance from the center of the wire in the number of radii that is used to determine when wires cross; Crossed wires will not compute correctly; Wires making up a junction should not be too dissimilar; The ratio should be less than 2; Differences greater than 5 should be avoided |

### 6.2.2 Patches

Guidelines for Individual patches have not been implemented.

Guidelines for patch/wire junctions have not been implemented.

There are two diagnostic options, as indicated by the radio buttons for Geometry and Electrical/ Solution.

If the Geometry diagnostic option is chosen, the Modeling Guidelines are checked against the geometry description for those issues that have been selected. For example, if only Individual Wires have been selected, only straight wires will be evaluated against the Modeling Guidelines. For Individual Wires, the check against the Modeling Guidelines indicates the wire number and the type of violation. For junctions, the check against the Modeling Guidelines indicates the node, the type of violation, and the wires involved. Special Wires uses the same format as Individual Wires. The two wires that are crossed are indicated.

If the Electrical diagnostic option is chosen, diagnostics can be used to check the electrical description of loads, transmission lines, and sources for valid geometry nodes.

The NEEDS Workstation has both intrinsic and extrinsic diagnostics. Many of the individual dialog boxes check for valid inputs.

The results of the Diagnostics is displayed in the text box. The results of the Diagnostics can also be displayed by selecting the Visualize button after running diagnostics. Wires that have warnings associated with them are color-coded in yellow. Wires that have errors associated with them are color coded in red. All of the remaining wires are displayed in white. A wire can be "picked" and highlighted. A text box is produced in which the "picked" wire is described along with a list of the warnings and errors associated with the wire. The wire and/or its nodes can then be edited to correct any problems.

### 6.3 NEC-MOM EXECUTE

The NEEDS Workstation interfaces with the Numerical Electromagnetic Code - Method of Moments (NEC-MoM), Version 4.0. When the user selects this option, NEC-MoM executes the NEC-MoM file on the same platform as the NEEDS Workstation. The NEC-MoM executable must be accessible. The executable file must be named "nec4s". It must be in the user's path. This option then transfers the user to NEC-MoM Run Status.

### 6.4 NEC-MOM RUN STATUS

This option allows the user to accomplish the following:

1. Determine the status of a given execution run of a NEC-MoM run
2. Determine the history of NEC-MoM executions during the current NEEDS Workstation session
3. Kill a currently running job

The status is updated using the Update List button. The Kill Job button kills the job highlighted in the upper list box. The Close button closes the window. If the user exits NEEDS and then restarts NEEDS, the NEC-MoM run status will allow the user to determine the status of NEC-MoM processes that are still executing.

## 7. RESULT

The output of NEC-MoM can be displayed as text, engineering plots, or 3-D visualizations.

### 7.1 TEXT

This option provides a listing of the output of NEC-MoM for the given input file. The user has the option of viewing all of the output or selected output. The NEEDS Workstation filters the output file generated by NEC-MoM, *"<ProjectName>.out"*, to provide the user-selected output. When the user selects an output option, the resulting text is saved as an ASCII file with the same name as the file-name for the output of NEC-MoM. The specific files are differentiated by their extensions. The output options and the extensions of the resulting text files are as follows:

1. All: *.out*
2. Impedance: *.rz*
3. Admittance: *.ra*
4. Currents: *.rcr*
5. Charges: *.rq*
6. Coupling: *.rcp*
7. Near Electric Field: *.rne*
8. Near Magnetic Field: *.rnm*
9. Radiation Patterns: *.rpt*

Currents, charges, near electric fields and near magnetic fields can be scaled by the input power.

If a NEC-MoM run does not execute completely, there will still be a ".out" file generated. This file can be read with the ALL option. All other options will not be available.

The user can direct the text file to a printer.

### 7.2 PLOT

The engineering plots are limited to 2500 data points. The specific engineering plots are described in the following sections.

#### 7.2.1 Impedance

The following engineering plots are available:

1. Resistance versus Frequency
2. Reactance versus Frequency
3. Smith Chart

The source number must be specified by the user.

#### 7.2.2 Admittance

The following engineering plots are available:

1. Conductance versus Wavelength
2. Susceptance versus Wavelength

The source number must be specified by the user.

#### 7.2.3 Currents

The following engineering plots are available:

1. Magnitude versus X
2. Magnitude versus Y
3. Magnitude versus Z
4. Magnitude versus Segment
5. Phase versus X
6. Phase versus Y
7. Phase versus Z
8. Phase versus Segment

The power, source number, and frequency must be specified by the user. The currents can be scaled by the total input power. If the input power is set to zero, the charges are not scaled. If the Tag is set to zero or not specified, all Tags are selected.

### 7.2.4 Charges

The following engineering plots are available:

1. Charge versus X
2. Charge versus Y
3. Charge versus Z
4. Charge versus Segment

The power, source number, and frequency must be specified by the user. The charges can be scaled by the total input power. If the input power is set to zero, the charges are not scaled. If the Tag is set to zero or not specified, all Tags are selected.

### 7.2.5 Coupling

This engineering plot plots Isolation versus Frequency.

### 7.2.6 Near Electric Fields

The following engineering plots are available:

1. Normalized z-component versus X
2. Normalized z-component versus Y
3. Normalized z-component versus Z
4. Normalized z-component versus Frequency
5. Total electric field versus X
6. Total electric field versus Y
7. Total electric field versus Z
8. Total electric field versus Frequency

Antenna power and the source number must also be specified.

### 7.2.7 Near Magnetic Fields

The following engineering plots are available:

1. Normalized z-component versus X
2. Normalized z-component versus Y
3. Normalized z-component versus Z
4. Normalized z-component versus Frequency
5. Total magnetic field versus X
6. Total magnetic field versus Y
7. Total magnetic field versus Z
8. Total magnetic field versus Frequency

Antenna power and the source number must also be specified.

### 7.2.8 Radiation Patterns

The following polar plots are available:

1. Vertical radiation component versus Theta
2. Horizontal radiation component versus Theta
3. Vertical radiation component versus Phi
4. Horizontal radiation component versus Phi

Source and frequency must also be specified.

Presently, there is no built-in option for printing the engineering plot. Use an individual platform's screen capture capability to print the engineering plot.

## 7.3 VISUALIZATION

Several 3-D displays are available to view the NEC 4.0 output data (Russell and Rockway, 1993). The user may select log or linear for most visualizations.

### 7.3.1 Geometry

The NEC-MoM input file describes the modeled object as a collection of wires. There are four windows that can be opened to display the model's input geometry. Each window displays one of the following:

1. Wire Segmentation (segment length in meters)
2. Wire Radius (meters)
3. Segment-to-Radius Ratio
4. Wire Connections (none, one, or both ends connected)

As depicted in figure 5 for segmentation, all of these windows display the model as a 3-D wire object. The data are encoded in the color of each wire segment using a user-selected linear or log

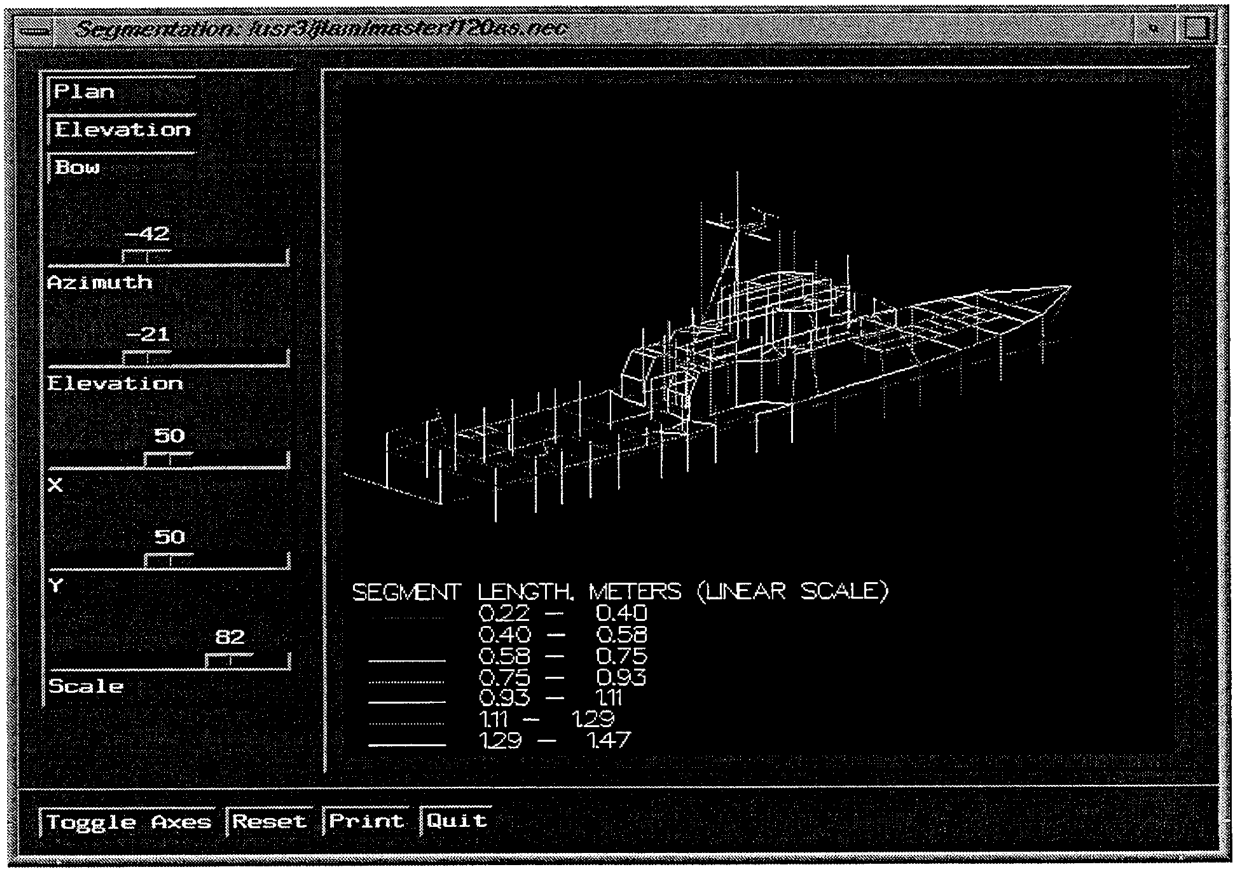


**Figure 5.** Segmentation visualization of a ship.

color assignment scheme. A color key is displayed on the left side of the window. The user can use the left button of the mouse and "pick" a segment to display information about the segment. The segment is highlighted by white stars bracketing the segment. This information includes the segment number and information about the wire. The wire information includes the coordinates of the end points of the wire, the radius, and the number of segments. The "pick" information window allows the user to quickly change either the node descriptions or the wire description. This pick capability is available for windows in which the model geometry is displayed, including the diagnostic visualization. Slider widgets on the left side of the display window allow scene transformations. This includes rotating, translating, and zooming the model. Plan, elevation, and bow orientations are directly available to the user. The model can also be reset to its initial condition.

### 7.3.2 Currents and Charges

Currents and charges on the wires are displayed using the same technique used for the Geometry Description products. Current or charge is color-coded on a 3-D wire display of the model. The user can select the following items.

1. Current Magnitude (linear or log)
2. Current Phase
3. Charge Magnitude (linear or log)

The source number, frequency and antenna power must be specified by the user.

#### 7.3.3 Fields

**7.3.3.1 Near Fields.** NEC-MoM allows the user to calculate the near fields at selected locations surrounding the model. These locations are usually defined by a 3-D grid surrounding the model. The near field is a complex vector. Of most interest is the z-component of E-normal or Total E-normal.

The near fields are displayed using a "point cloud" technique in which the density of activated pixels in the image is proportional to the field intensity at the nearest calculation point. The point cloud is color-coded in a manner similar to the geometry description products. The 3-D wire model is drawn using a dark gray color so as not to detract from the near-field display. The source number, frequency, and antenna power must be specified by the user.

**7.3.3.2 Radiation Patterns (E-Theta, E-Phi).** There are two windows available for the display of radiation patterns. These windows allow the user to display either the theta component or phi component of the radiation pattern. The radiation pattern is complex data. The radiation pattern is displayed on a 3–D surface. The distance from a point on the surface to the origin is proportional to the field magnitude at that point. The color at the point is determined by the phase of the field at that point. The source number and frequency must be specified by the user.

# 8. OUTPUT

This capability has not been implemented.

# 9. MISCELLANEOUS TOPICS

## 9.1 MODELING PROCESS

There are several steps to the method-of-moments modeling process. The following sections describe these steps sequentially.

### 9.1.1 Defining The Geometry

There are two principal methods in defining the geometry using NEEDS. First, the text input of the geometry description can be used. The options available for this textual description are available in Geometry Description under Input on the Main Menu bar and include the following items.

1. Node Coordinates - Ctl+N
2. Straight Wires - Ctl+W
3. Tapered Wires - Shf+W
4. Catenary Wires - Ctl+C
5. Wire Arc - Ctl+A
6. Helix or Spiral
7. Mesh - Ctl+Z
8. Surface Patches

9. Multiple Patches
10. Transformations - Ctl+T
11. Rotations - Shf+T
12. Reflections - Ctl+R
13. Spiral Ordering . . .
14. CAD Interface
15. Edit Card Order

Using Geometry Description, the geometry nodes must first be defined. These nodes are then used in many of the remaining Geometry Description options.

The second option is to use a separate CAD package and then use the CAD Interface to input the CAD geometry description into NEEDS. CAD Interface is also available under Geometry Description.

### 9.1.2 Evaluating the Validity of the Geometry

The geometry description can be evaluated using the Diagnostics option under the Execute option of the Main Menu bar. To adequately evaluate the geometry description, the frequencies for the problem should also be defined.

### 9.1.3 Defining the Electrical Description of the Problem

The options for defining the electrical description of a problem are available under Edit Control Cards under Input on the Main Menu bar and include the following options for control cards:

1. Frequency (FR)
2. Loads (LD)
3. Voltage Sources (EX)
4. Incident Plane Wave (EX)
5. Transmission Lines (TL)
6. Two-Port Networks (NT)
7. Insulated Wire (IS)
8. Ground Parameters (GN)
9. Additional Ground Parameters (GD)
10. Upper Medium Parameters (UM)

### 9.1.4 Evaluating the Validity of the Electrical Description

The electrical description can also be evaluated using the Diagnostics option under the Execute option of the Main Menu bar.

### 9.1.5 Defining the Desired Solution Description

The options for defining the solution description of a problem are also available under Edit Control Cards under Input on the Main Menu bar and include the following control card options:

1. Maximum Coupling (CP)
2. Near Electric Field (NE)
3. Near Magnetic Field (NH)
4. Radiation Patterns (RP)
5. Print Options For Charge (PQ)
6. Print Electrical Lengths (PS)
7. Print Options for Current (PT)
8. Execute (XQ)

It is recommended that at this point the user look at the Description Summary under the Execute option of the Main Menu bar. This option gives the user an overall description of the problem.

### 9.1.6 Running NEC-MoM Computation

The user needs to save the problem description. This option is available under the FILE option of the Main Menu bar. This option also saves a file which can be used as the input to the NEC-MoM code. The name of this file is *"<ProjectName>.nec"*, where *"<ProjectName>"* is the name of the project.

If the user wishes to run the NEC-MoM code that is available on the same platform as the NEEDS system, the user exercises the NEC-MOM EXECUTE option under Execute on the Main Menu bar. The NEC-MoM executable must be accessible. The executable must be named "nec4s". It must be in the user's path.

The option NEC-MOM RUN STATUS can be used to monitor the status of the NEC-MoM run.

### 9.1.7 Evaluating Results

The NEEDS system provides several options for viewing the results of the NEC-MoM computation. These options are available under the RESULT option of the Main Menu bar. These options include:

1. Text
2. Plot
3. Visualization

## 9.2 NEEDS LIMITATIONS

The user should be aware of several limitations in the NEEDS Workstation. These limitations include the following:

1. The NEEDS Workstation is not a CAD package for the development of a method-of-moments compatible geometry model. There is a separate methodology for developing a NEC - MoM

compatible geometry model. The CAD Interface option is an attempt to interface to this methodology. The methodology to support the topside integration efforts of the Navy is under development.

2. The NEEDS Workstation was developed to support the topside integrations efforts of the Navy. Therefore, some of the NEC-MoM options were not developed. As an example, presently the reflection, rotation, and transformation geometry options are not supported by the visualization options of the NEEDS Workstation. Several NEC options are also not supported. These include the GF - Read a NGF file, VC - Voltage - Source End Caps, and WG - Write NGF File. In addition, the extended options of the XQ - Execute option are not available in the NEEDS Workstation.

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13. ABSTRACT *(Maximum 200 words)*

This manual assists the user with the operation of the Numerical Electromagnetic (EM) Engineering Design System (NEEDS 3.1). The Numerical Electromagnetic Code – Method of Moments (NEC–MoM), Version 4.0, is the principal computational tool for determining the shipboard EM environment in the high-frequency through very-high frequency bands. The use of NEC–MoM for antenna system and EM environment evaluation is a lengthy, tedious, and error-prone process. NEC–MoM requires rigidly defined inputs and produces large masses of output data. NEEDS 3.1 was developed to assist in making the method-of-moment process less tedious and more error-free.

14. SUBJECT TERMS

Numerical Electromagnetic Engineering Design System (NEEDS)
Numerical Electromagnetics Code – Method of Moments (NEC–MoM)
Simple Raster Graphics Package (SRGP)
Computational electromagnetics

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